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TRANSACTIONS

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AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

VOL. XXXII.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

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714.

(Vol. XXXII.—July, 1894.)

CHAUTAUQUA, N. Y., SEWAGE DISPOSAL WORKS.

By WILLIAM B. LANDRETH, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

Chautauqua, N. Y., is a well-known summer resort on the southwest shore of Chautauqua Lake. The grounds run over a mile along the lake shore, and extend back from the lake for half a mile. There are about 10 miles of streets and avenues through which water pipes were laid several years ago.

Prior to 1893 the sanitary arrangements of the grounds were very crude. Public crematory closets were placed at various points, and cesspools were largely used as a means of disposing of the kitchen wastes. The rough garbage was drawn to the southern part of the grounds by the authorities, dried and burned. The cost of those methods of disposal was $2 000 for the season of three months, and the results were very unsatisfactory. A complete system of separate sewers was designed by Samuel M. Gray, M. Am. Soc. C. E., and built during the fall and winter of 1892 and 1893, under the direction of Thomas McKenzie, Jun. Am. Soc. C. E., as Engineer in Charge

for Mr. Gray. The sewers are from 8 to 20 ins. in diameter, with manholes at changes of grade or line, and no flush tanks.

Most of the grades are steep, and the large number of automatic public closets furnish the necessary flushing.

The main sewer extends nearly to the southern limit of the grounds, where it is 5 ft. above the mean lake level and 200 ft. from the shore. The question of the disposal of the sewage presented the problem of providing a means of purification that would prevent the slightest contamination of the lake, the purity of whose waters have been protected by rigid State laws.

The depth of the sewers and the steep slope of the hill side at its end prevented the use of any method of land filtration, leaving the only choice to some chemical method.

In October, 1892, the Assembly authorities advertised for plans and bids for erecting a complete system of sewage disposal, each plan to be accompanied by a bid for building the works in accordance therewith. The plan and bid submitted by the writer was accepted by the Trustees of the Assembly at their annual meeting in Pittsburgh, Pa., January 17th, 1893, and, after some changes suggested by Mr. Gray had been made in the plans, the contract was signed for the erection of the works.

Work was begun April 1st, 1893, under the supervision of Mr. Thomas McKenzie, Resident Engineer, and the plant was in operation the first week in July.

General Plan.—The works as built consist of a machine house, 40 x 40 ft., and four precipitation tanks and the necessary machinery for handling the chemicals and sludge.

The sewage enters the machine house on the west side in a brick channel 24 ins. wide, with a circular cross-section on the bottom. A screen made of iron bars, 1¼ x ¼ ins. spaced ¾ in. apart, set in the channel, catches all of the larger particles, which are raked off and burned under the boiler.

Two wooden chemical mixing vats, holding 850 galls. each, provided with revolving arms, are set near the inlet channel, to which they are connected by 3-in. iron pipes. The first vat contains milk of lime, for which the lime is slaked in a small vat suspended over it. The second vat contains a solution of sulphate of alumina, which is formed from crystal alum. The chemical pipe from each vat is pro-

PLATE I.
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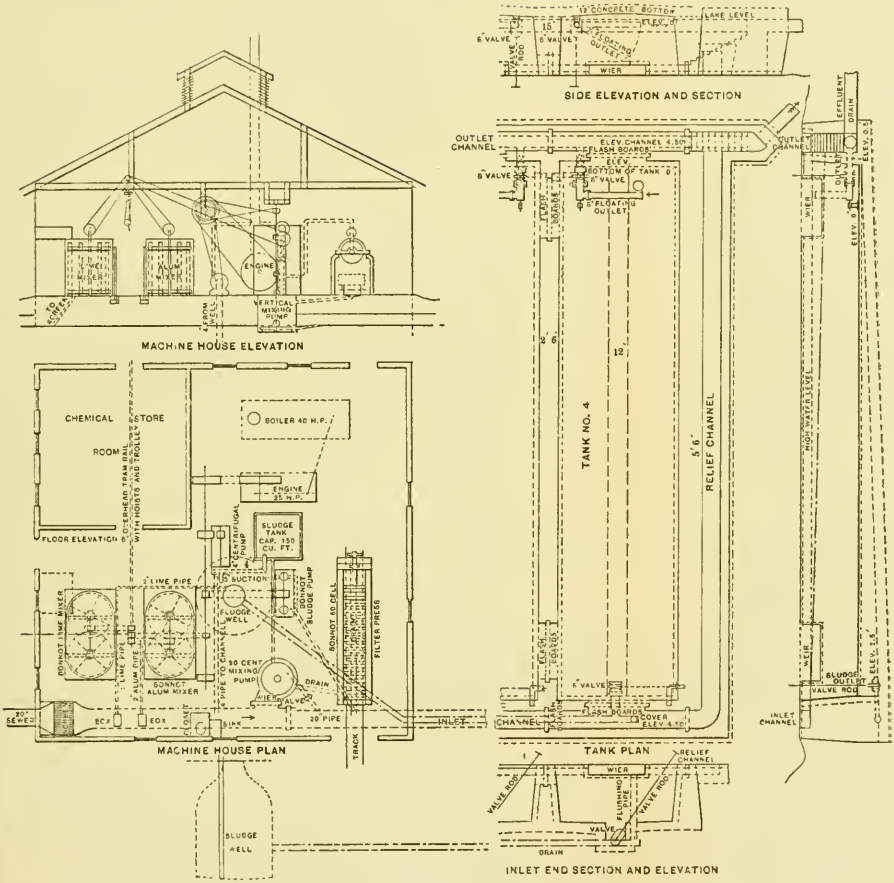
VOL. XXXII, No. 714.
LANDRETH ON CHAUTAUQUA SEWAGE DISPOSAL.



vided with an iron box at the channel end, from which the solution flows into the inlet channel over a measuring weir 4 ins. wide.

The quantity of solution passing into the sewage over the small weirs can be determined very quickly by noting its height on a scale at one end of the weir, and the proper amount necessary for the sewage flow easily regulated.

After receiving the chemicals, the sewage passes over a weir 2 ft. long, where it is measured, and enters a mixing well, where a vertical centrifugal pump thoroughly agitates it and throws it into the inlet channel again, thus insuring a perfect mixture of the sewage and chemicals. Passing along the inlet channel, the mixture enters the main channel of the tanks.

Tanks.—There are four tanks, each 12 by 56 ft. inside, with 4½ ft. depth of water. The walls are of stone masonry laid in natural cement, lined with 8 ins. of hard brick laid in Portland cement, and are capped with sawed sandstone flagging 3 ins. thick. A main inlet channel extends along the end of the tanks, and carries the sewage into any of them over weirs 6 ft. long; and a similar outlet channel along the other end of the tanks discharges the effluent over steps into a 15-in. outlet extending into the lake. The end walls are 4 ft. on top and 5 ft. at the bottom; the side walls 2 ft. on top and 3 ft. at bottom, and the partition walls are 2 ins. thicker.

The tank bottoms are of concrete 12 ins. thick, made of 1 part of natural cement, 2 parts of sand, and 3 parts of broken stone; they slope from the sides with a fall of 1 in 30 to a central sludge channel 2 ft. wide, which has a fall of 2 ft. 6 ins. in the length of the tank to the sludge outlet.

A 15-in. low level outlet pipe is built in the outlet end wall, and is connected with each tank by an 8-in. iron pipe, which is fitted with a Ludlow valve and a galvanized iron hinged outlet pipe, the mouth of which is kept just under the surface of the water by a float. The several weirs and flash boards are so arranged that the tanks may be run in series or intermittently, as may be desired.

A relief channel runs along the outside of the last tank, allowing the night flow of clear ground-water to be run directly to the outlet, it having been found that the night flow stirs up the sewage already in the tanks, preventing settlement.

Method of Working.—When any tank is to be cleaned, the sewage is

cut out of it by the flash boards, and after a rest of about an hour for settling the sludge, the outlet valve is opened and the effluent drawn off till the sludge is reached. The outlet valve is then closed, and a sludge valve at the foot of the sludge channel opened, when the sludge flows through an 8-in. sludge drain, built in the inlet wall of the tanks, to the sludge well.

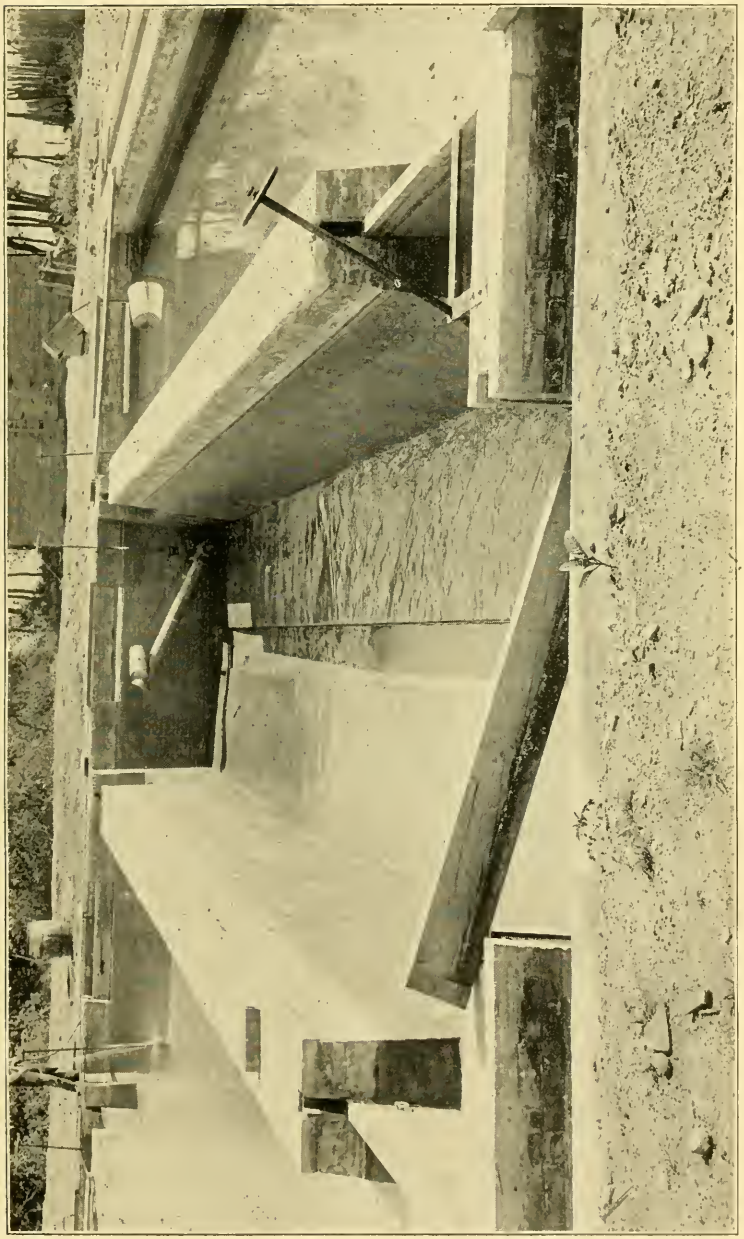
The sludge well is 16 ft. deep, 8 ft. in diameter, with brick walls 12 ins. thick, and is fitted with an iron manhole cover in the machine house floor. The sludge is pumped from the sludge well by a 4-in. Van Wie centrifugal pump into a sludge tank set on the machine house floor, holding 150 cu. ft. The sludge is allowed to settle in this tank and the clear water on top is drawn off by a skimmer pipe, added since the completion of the works. When ready for pressing, the sludge is forced into a 60-cell filter press by a power pump having two solid plungers and ball valves made of hard rubber, flat valves having proved a failure. The valves are easily accessible, the chambers being fitted with detachable covers.

The press has 60 steel chambers 30 ins. in diameter, with a 4-in. hole in the center of each, forming a continuous passage from end to end of the press.

A coarse jute sack is suspended between the chambers, which are faced with rubber, to prevent the cutting of the sacks or squirting of the press liquor. The chambers rest on the frame of the press on small wheels, and are held in contact with each other by pressure applied by a screw and hand wheel at the end of the press.

When the sludge is forced into the end of the press, the water passes out between the chambers along small channels in the lower faces of the cells and through the longitudinal meshes of the sacking, leaving the coarser particles of sludge between the faces of the chambers of the press. When the press is full of sludge cake, the pressure gauge on it shows a pressure of about 60 lbs., that being the point at which the relief valve on the force pipe is set, and the water ceases to flow from the drips of the press. The press screw is released by a lock nut, a car run under the press and, as the chambers are separated from one another, the cakes fall into it, and, when full, it is run out of the building and emptied.

The cakes are 30 ins. in diameter and 1½ ins. thick. When taken from the press they weigh 21 lbs., and when thoroughly dried the



weight is reduced to 12 lbs., showing 43% of moisture in them when taken from the press.

The sludge has been used by the Assembly authorities and neighboring farmers as a fertilizer. The tanks were operated in series, after experiments had proved that the better method.

The works were operated from July 1st to October 1st, during which time the daily flow was from 125 000 to 150 000, with about 75 000 galls. of ground-water.

The number of people using the sewers was from 3 000 to 7 000, with a probable average of 4 000; and from the water works pumping records the daily consumption of water was about 20 galls. per capita.

Profiles of gaugings show an hourly maximum of a little more than 6 % of the daily flow; while from midnight to 5 A.M. the flow was clear ground-water. During heavy storms considerable rain water entered the sewers, probably through holes in the manhole covers and from a few roofs.

Chemicals.—The lime used was the Lighthouse brand of Marblehead lime, from Sandusky, O., and its cost was 83.2 cents per barrel delivered at the works, or .416 of a cent per pound. The alum was in the form of white crystals, costing 2.15 cents per pound. During the 92 days that the works were in operation, 29 500 lbs. of lime, 6 400 lbs. of alum, and one barrel of copperas were used. Large amounts of chemicals, especially alum, were used during July, in experimenting, to determine the proper proportions necessary, and the cost of operation was increased thereby.

After the experimental period was passed, the amounts used daily were one barrel of lime, 30 to 40 lbs. of alum, and 2 to 5 lbs. of copperas.

Cost of Operation—Labor.—The men employed at the works were: One superintendent and engineer at $85 per month; one helper a part of the time, from 7 A.M. to 6 P.M., and a watchman from 6 P.M. till 7 A.M., each of whom received 12½ cents per hour. The total labor bill for 92 days was $386, or a little less than $4.20 per day. For the population of 4 000 this would give a little over one-tenth of a cent as the per capita daily cost of labor.

Oil, Chemicals, etc.—Fuel, oil and waste cost about 40 cents per day. The total cost of chemicals was $269 52 for the entire season, or an apparent daily cost of $2 87, but as large amounts of chemicals were

used in experiments in July, the cost per day of chemicals during August and September was probably about as follows:

One barrel of lime	$0 83
35 lbs. alum	0 75
3 lbs. copperas	0 12

making a total of $1 70 per day. On the above basis the total daily cost, after the experimental stage, would be: Labor, $4 20; fuel and oil, etc., $0.40; chemicals, $1 70, giving a total of $6 30. For an average attendance of 4 000, the daily capita cost would be .157 of a cent or $0.573 per capita per year, to which should be added an interest charge of $0.165, making a total per capita cost of $0.738 per year.

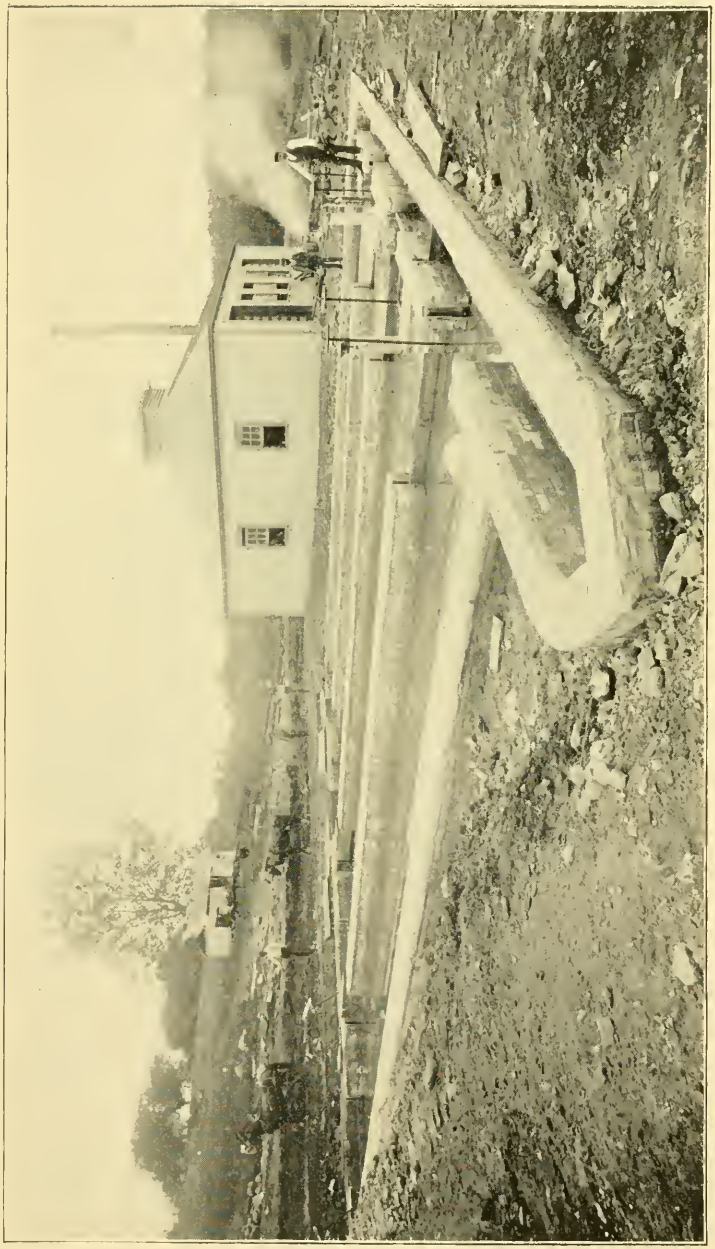
Chemical and Physical Results.—After July 28th, the effluent was uniformly clear and odorless. Samples of the sewage and effluent were taken at 4 P. M., September 25th, after the night flow had left the tanks, and were carefully sealed and sent to Prof. Maurice Perkins, Union College, Schenectady, for analysis. The samples were delayed in transit and did not reach the laboratory till September 29th, and on October 9th, Prof. Perkins reported as follows:

CHEMICAL LABORATORY, UNION COLLEGE,
SCHENECTADY, N. Y., October 9th, 1893.

Report of the results of the chemical analysis of a specimen of crude sewage and the effluent after treatment, received from W. B. Landreth, C. E., from Chautauqua, New York.

	Parts in 100 000. Crude sewage.	Effluent.
Appearance	Turbid.	Clear.
Color	Light grayish.	None.
Odor	Urinous.	None.
Total solid residue	117	23.6
Mineral matter (after incineration)	59.2	14.4
Loss on incineration (organic matter)	57.8	9.2
Chlorine	6.0129	6.0129
Corresponding chloride of sodium (common salt)	9.97	9.97
Free ammonia	2.428	1.3568
Albuminoid ammonia	2.088	.4856
Phosphates	Strong reaction.	None.
Nitrates	Not detected.	Not detected.
Nitrites	" "	" "

MAURICE PERKINS,
Professor of Chemistry in Union College.



UNION COLLEGE,
SCHENECTADY, N. Y., October 9th, 1893.

WILLIAM B. LANDRETH, Jamestown, N. Y.

Dear Sir,—I have delayed reporting the results of the chemical analysis of the specimens received September 29th because I wanted to make some observations on them after standing some time.

The analyses were made as soon as possible after their receipt. To-day I made another partial analysis of the crude sewage. This was to explain some of the results of the first.

Let me first speak of the treated sewage or effluent. This is the first "effluent" that I have ever seen that did not undergo change, such as to make it muddy and smell badly. To-day though the bottle, half full, has been kept in the laboratory, at the ordinary temperature of a room at this period of the year, the fluid is as clear and to the senses as unoffensive as at the first moment of receipt. How thorough the removal of solids and putrescible matter has been you can see by the comparison of the two analyses.

The analysis of the crude sewage shows large quantities of free ammonia. Larger amounts of this than of the albuminoid were present, but in the effluent you will see there was much less ammonia. It would be difficult by any process to remove the ammonia from the crude sewage. So this found in the specimen sent me above that in the effluent must have been formed during the time which elapsed between its collection and my analysis (three days). When the reagents used in the process struck the original or crude sewage, nearly one-half of the nitrogen, which I found in the form of free ammonia, must have been in the albuminoid form and precipitated by them. Thus removed before the change had occurred.

The crude sewage contained some finely divided paper, which, of course, left an ash on incineration. This in part accounts for the high ash account of the crude sewage. But it is this as well as other materials which you desire to remove by your process.

In conclusion, if you can furnish such an effluent, I do not see how it can become offensive.

Respectfully yours,
MAURICE PERKINS.

The concentrated character of the sewage is shown by the total solid residue of 117 parts in 100 000, as might be expected from the low water consumption. The analysis shows that 80% of the total solids and 76.6% of the albuminoid ammonia were removed.

The writer is aware that the result shown might not have been obtained continuously and probably was not, and gives the analysis simply as that of one sample each of sewage and effluent. During the

present season daily examinations of the sewage and effluent will be made chemically and biologically by a careful and experienced observer, and measurements of the sewage will be taken by a recording gauge. The amount of pressed sludge produced was about 0.8 lb. per capita daily. The total cost of the works was $16 500, exclusive of the land, including 150 ft. of iron outlet laid on the bottom of the lake. The chemical mixers, sludge pump and sludge press were built by the Bonnot Company, of Canton, O., which also furnished and erected the shafting, pulleys and piping.

This description of the works and the results obtained are given simply as showing the way in which the problems presented were solved, and not as a guide for all cases, as the writer is fully aware of the limitations of chemical precipitation of sewage.

The results obtained seem to have been in part due to (1) the thorough mixing of the sewage and chemicals; (2) the careful gauging of sewage and chemicals and their proper proportioning, and (3) to the design of the tanks by which the course of the sewage is positive and the formation of cross currents prevented.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

715.

(Vol. XXXII.—July, 1894.)

THE CIPPOLETTI TRAPEZOIDAL WEIR.

By A. D. FLINN and C. W. D. DYER.*

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

NOMENCLATURE.

A = area of vertical cross-section of water in canal of approach at point of measurement of H.

C = coefficient in formula for Q.

c = coefficient of contraction, according to Cippoletti; called by American authorities coefficient of discharge.

g = acceleration of gravity = 32.1644.

$$\sqrt{2g} = 8.0205. \quad \frac{1}{2g} = 0.01555.$$

G = depth from crest of weir to bottom of canal of approach.

* In preparing this paper the writers have made use of the following books and pamphlets: J. B. Francis, "Lowell Hydraulic Experiments"; Hamilton Smith, Jr., "Hydraulics"; Mansfield Merriman, "Treatise on Hydraulics"; L. G. Carpenter, "Bulletin No. 13, Colorado State College"; Cesare Cippoletti, "Canal Villoresi; Modulo per la Dispensa delle Acque"; Engineering *Record*, August 13th, 1892; *Transactions* of Am. Soc. C. E., Vol. XII, 1883, p. 55, Fteley and Stearns.

$H =$ head measured by hook-gauge.

$h =$ effective head.

$h_a =$ head corresponding to velocity of approach.

$L =$ horizontal distance from end of sill to the nearer side of the canal of approach.

$l =$ measured length of sill.

$M =$ leakage from canal of approach to Francis weir during an experiment.

$q =$ quantity of water discharged during an experiment, as measured by the Francis rectangular weir.

$q' = q + M$. $Q_1 =$ approximate discharge per second.

$Q =$ discharge per second. $Q = \frac{q'}{t}$.

$t =$ time in seconds.

$V_a =$ mean velocity of approach. $V_a = \frac{Q_1}{A}$.

$e\,v\,h =$ extreme variation in head during an experiment.

$$h = H + b\,\frac{V_a^2}{2\,g} = H + b\,h_a.$$

$b = 1.4$ for weirs with full contraction.

$$\therefore h = H + 1.4\,h_a.$$

$$q = t \times \tfrac{2}{3}\sqrt{2\,g} \times 0.623\,(l - 0.2\,h)\,h^{\frac{3}{2}}.$$

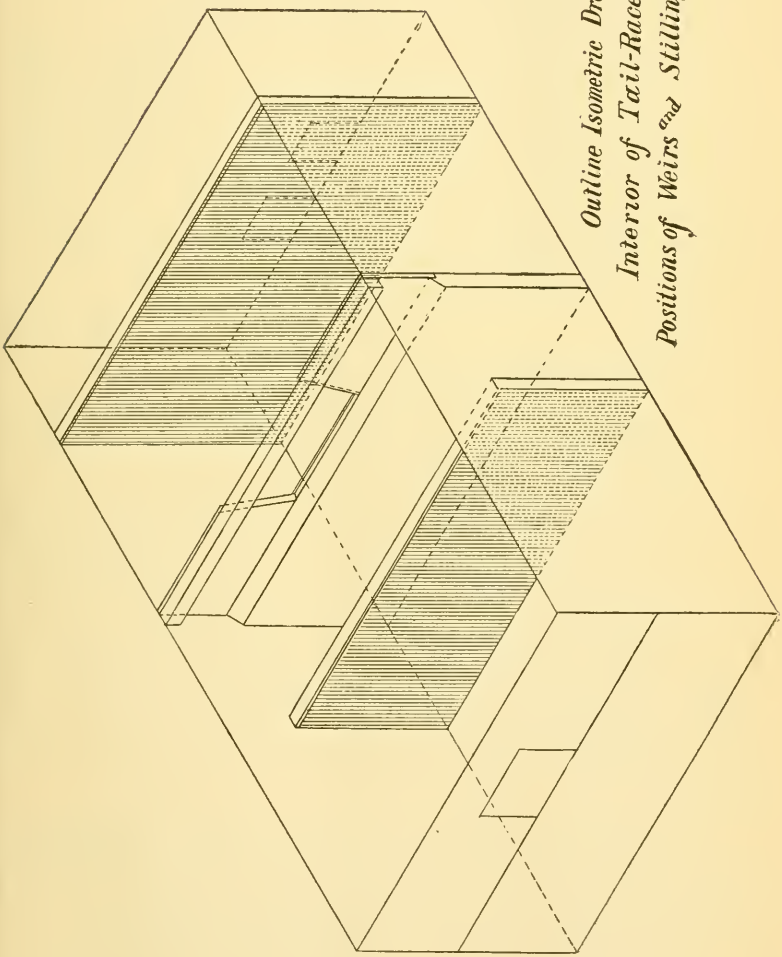
$$= t \times \tfrac{10}{3}\,(l - 0.2\,h)\,h^{\frac{3}{2}} \text{ (very nearly).}$$

$$q_1 = t\,c\,\tfrac{2}{3}\sqrt{2\,g}\,l\,h^{\frac{3}{2}} = 5.347\,t\,c\,l\,h^{\frac{3}{2}}.$$

$$C = \frac{Q}{l\,h^{\frac{3}{2}}}.$$

$$c' = \frac{C}{\frac{2}{3}\sqrt{2\,g}} = \frac{C}{5.347}.$$

The Weir.—The weir with complete contractions was formerly considered to be the most accurate and convenient means for measuring large quantities of water. The form commonly used has been the rectangular weir with horizontal sill and vertical sides and with three complete contractions. With this form of weir, the coefficient of discharge is not constant, but increases with the length of the weir and diminishes when the head on the sill increases. Furthermore, because of the effect of end contraction, with equal heads, the quantities discharged are not proportional to the length of sill; and with constant sill length, the discharge does not vary proportionally to any power of



Outline Isometric Drawing of Interior of Tail-Race Showing Positions of Weirs and Stilling Racks.

the head, because of the effect of bottom contraction. These facts constitute objections to the rectangular weir. When the Villoresi Canal was projected in 1881, the government of the province of Milan, Italy, regarded these objections as sufficiently serious to make another form of module desirable. Consequently the engineer, Signor Cesare Cippoletti, was instructed to devise a module, based upon the theory of the weir, which should be free from these difficulties.

The problem which Cippoletti set himself to solve was to determine the conditions of a weir which would measure the discharge with an error, due to any one cause, not greater than $\frac{1}{2}$ % and at the same time retain the simple formula, $Q = C\,l\,h^w$. He adopted the results of the Lowell experiments of Mr. J. B. Francis as the basis of his investigations, supplementing them with the works of some other hydraulicians, and with data from experiments of his own made for the purpose of discovering the effects of variations in certain details of construction.

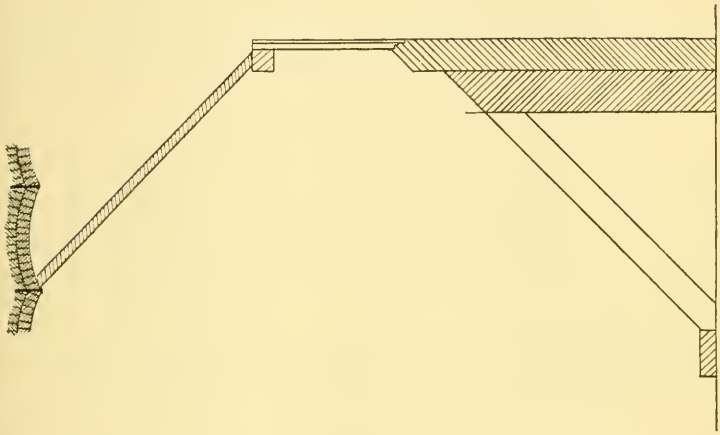
Commenting upon the variations of the coefficient of contraction in the Francis formula, Cippoletti says:

"The cause of such variation of the coefficients is easily revealed by the fact that, while in the common formula there is a single coefficient of contraction, the phenomenon is double, since there is proof of a superficial and a lateral contraction; and if the first is proportional to the breadth of the stream and is found to be represented in the formula, the second instead is proportional to the depth of the vein, and has no factor in the usual formula which takes account of it. From this it follows that the incomplete common formula is forced to represent also the variations of the discharge depending upon the varying depths of the vein; the coefficient of horizontal contraction is obliged to assume diverse values, while from its nature it would be constant. The questions hence reduce themselves to separating the two contractions and representing each in the equation of discharge by proper terms."*

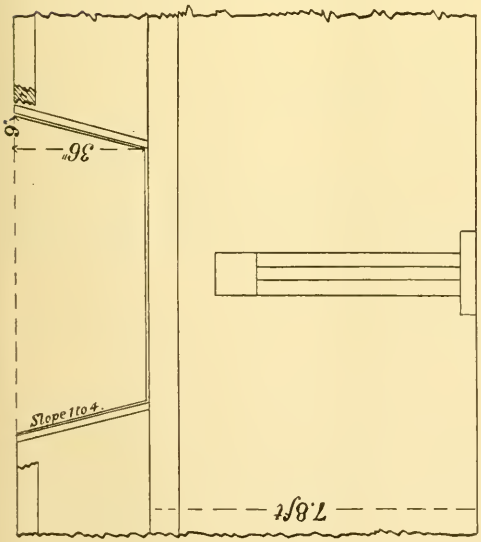
To overcome the difficulty here described, Cippoletti concluded to eliminate the effects of end contraction automatically by a modification in the shape of the weir. Instead of making the ends vertical as in the rectangular weir, he gave to them a slope of one horizontal in four vertical, as determined by the following mathematical deduction:

"Keeping in mind, as ascertained, that the effect of this (end) contraction is proportional to the depth of the stream, and equivalent to

* Translated from "Canale Villoresi," etc.



Section on Center Line.



Front Elevation.

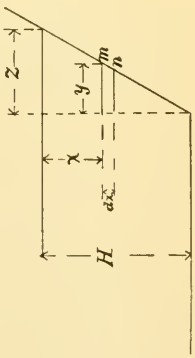


Figure A.

diminishing the breadth one-tenth of the depth, nothing prevents the ends of the weir, instead of being vertical, being inclined outward in such a way that the water which passes through the two triangles may compensate exactly, for each head, for the loss caused by the lateral contraction. This is equivalent to constructing a weir of trapezoidal form, in which the inferior base is assumed as the breadth, and the discharge is given by the common formula,

$$Q = c\, l\, \tfrac{2}{3} \sqrt{2\, g}\, h^{\frac{3}{2}},$$

in which, therefore, there came to be assumed for c the constant value of the horizontal contraction alone, found by Mr. Francis to be 0.623.

There remains to determine what should be the inclination to apply to the sides of the stream in order that the discharge through the two lateral triangles may be equivalent to compensating for the effect of the lateral contraction.

In Figure *A* (Page 13) let $m\, n$ represent an element at the depth x, below the surface; its area will be—

$$y\, d\, x = \frac{h - x}{h} \,.\, z\, d\, x.$$

Its discharge will be expressed by—

$$d\, Q = c \frac{h - x}{h} \,.\, z \sqrt{2\, g\, x}\, d\, x = c \frac{z}{h} \sqrt{2\, g}\, (h\, x^{\frac{1}{2}}\, d\, x - x^{\frac{3}{2}}\, d\, x).$$

Integrating—

$$Q = c \frac{z}{h} \sqrt{2\, g}\, (\tfrac{2}{3}\, h\, x^{\frac{3}{2}} - \tfrac{2}{5}\, x^{\frac{5}{2}}).$$

Taking this between the limits $x = h$ and $x = 0$, we have—

$$Q = c \frac{z}{h} \sqrt{2\, g}\, (\tfrac{2}{3}\, h^{\frac{5}{2}} - \tfrac{2}{5}\, h^{\frac{5}{2}}) = c\, z \,.\, \frac{4}{15} \sqrt{2\, g}\, h^{\frac{3}{2}}.$$

From the other part of the Francis formula we have that the diminution of the discharge due to the effect of the lateral contraction on one side is as follows:

$$c \,.\, 0.10\, h \,.\, \tfrac{2}{3} \sqrt{2\, g} \,.\, h^{\frac{3}{2}}.$$

For which reason the two quantities are equivalent, so that—

$$c\, z\, \frac{4}{15} \sqrt{2\, g}\, h^{\frac{3}{2}} = c \,.\, 0.10\, h\, \tfrac{2}{3} \sqrt{2\, g}\, h^{\frac{3}{2}} \text{ ; whence}$$

$$z = 0 \,.\, 25\, h.$$

That is to say, it is sufficient to construct the weir with the sides inclined at $\frac{1}{4}$ in 1, in order that for every depth of the stream the effect of the lateral contractions may always be compensated for by the water that flows through the lateral triangles, and, as we desired, without need of taking account of it in the formula."*

* Translated from "Canale Villoresi," etc., pages 37 and 38.

The conditions necessary to be fulfilled for this weir in order that no one cause may produce an error greater than $\frac{1}{2}$ % are the same as are usual for rectangular weirs with complete contraction. And the head should be read to within one-three-hundredth of the depth on the sill. The weir must not vary more than 4° from being perpendicular to the axis of the canal. From a study of causes of inaccuracies, Cippoletti concludes that Francis' coefficient should be increased one per cent. Hence, the formula for discharge for the trapezoidal weir becomes, in English units, assuming the coefficient of contraction to be, as determined by Francis, 0.623,

$$Q = 3.36\tfrac{2}{3}\, l\, h^{\frac{3}{2}}.$$

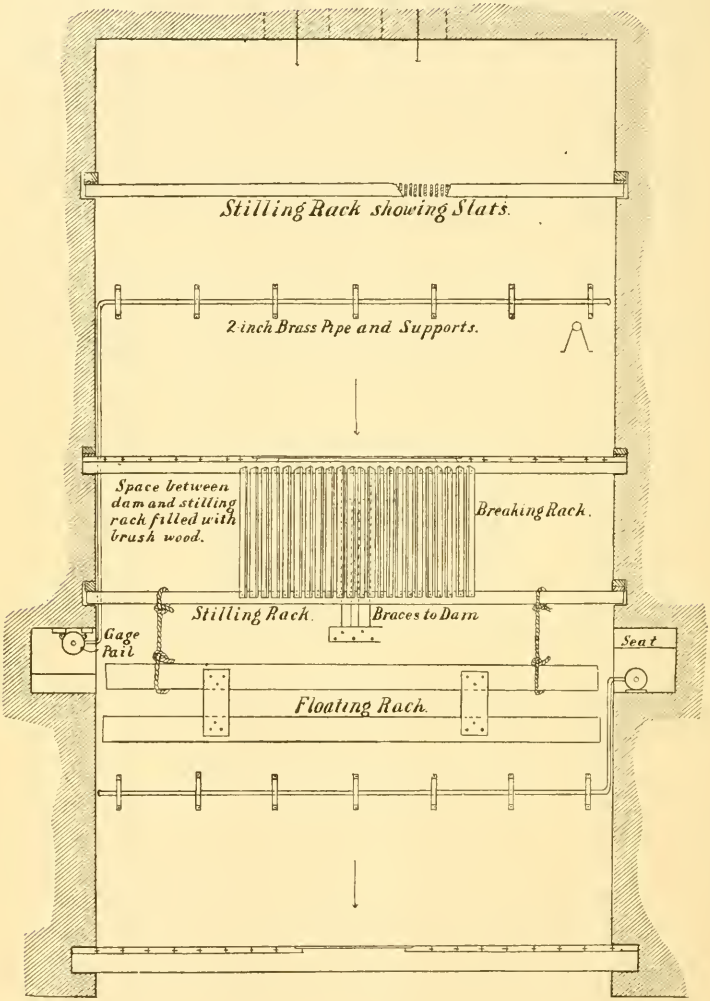
As far as the writers have been able to ascertain, the only experiments that have been made to test the reliability of this coefficient are those of Prof. L. G. Carpenter, of the Colorado State Agricultural College, on weirs 6 ins. and 12 ins. long, and a few laboratory experiments made during the winter of 1891–92, by Mr. T. McE. Vickers, with weirs 0.3 ft., 0.6 ft. and 0.9 ft. long, at Cornell University. Both these experimenters found that, within the limits of their experiments, Cippoletti's formula gave results not liable to an error of more than one per cent.

Thinking the field to be an interesting one for experimental research, the writers determined, if possible, to make some tests on a practical scale.

The Holyoke Water Power Company kindly granted them the use of their testing flume, and thus afforded as good conveniences for such a series of experiments as they have conducted as could probably be had anywhere, except at very considerable expense.

The Flume and Apparatus.—The flume at which the experiments were conducted is situated on the north side of the second level canal of the Holyoke Water Power Company, Holyoke, Mass., and is used by this company to test water wheels. The building was erected in 1881, under the direction of Clemens Herschel, M. Am. Soc. C. E.

The whole structure rests on a good foundation of piles. Water is admitted to the building through a flume 9 ft. in diameter, and from the receiving reservoir, flows through two gates into the wheel pit, whence it passes into the tail-race, where the experiments were conducted, and thence out into the canal, over the rectangular weir used by the Water Power Company.


Stilling Rack showing Slats.
2 inch Brass Pipe and Supports.
Space between dam and stilling rack filled with brush wood.
Breaking Rack.
Stilling Rack.
Braces to Dam
Gage Pail
Seat
Floating Rack.

The same difficulty presented itself here that has been encountered in all weir experiments of any magnitude, except those of Mr. J. B. Francis and Messrs. Fteley and Stearns, that of having a basin large enough to measure the water. It was impossible in this case to have a basin of more than about 2 400 cu. ft. capacity; besides, no by-pass could be arranged for the waste water, and so it was decided to make the quantity measurements over the rectangular weir of the Water Power Company. This weir was set with great care, and complies with all the requirements determined by Mr. Francis. Hence the writers feel satisfied that measurements made with it may be relied upon as reasonably accurate.

The basin in which the two weirs were set is 35.5 ft. long and 20 ft. wide, of constant cross-section.

The walls and bottom are covered with cement, making them very nearly water tight. The weir on which the experiments were made was placed 19.2 ft. back of the rectangular weir, and was set in a temporary dam of dry spruce timbers 21 ft. x 8 ins. x 8 ins., the ends of which were built into the wall on either side. The top timber of the stationary part of the dam was beveled at an angle of 45° and was grooved at the up-stream edge on top so as to receive the lower ends of the weir boards, which were 36 ins. high, 12 ins. wide, and 2 ins. thick. These were made water tight by mortising each and driving in a spline of well-dried white pine between adjoining boards. The up-stream face of the dam was a vertical plane, perpendicular to the axis of the basin. The dam was well braced at the center in front by an upright timber 12 x 12 ins., which was shored to a cleat in the floor. The weir boards were held in position by a 6 x 6-in. timber placed horizontally 3 ft. above the sill of the weir and securely braced against the roof, which is made of I beams and masonry because the tail-race extends under a spur freight track.

The sill and sides of the weir were made of $\frac{3}{8}$-in. wrought iron beveled 45° to 0.1 in. and carefully countersunk into the up-stream face of the dam. The sill piece was 10 ft. 6 ins. x 5 ins.; the two side pieces 3 ft. x 3 ins. All three presented clean, sharp edges to the water. Each side piece was fastened to its weir board by three screws passing through three slots, and thus giving opportunity for accurate adjustment to the proper inclination. A stilling rack was placed 11 ft. back of the trapezoidal weir, and another 13 ft. 6 ins. back

of the rectangular weir, to direct the threads of water parallel to the sides of the basin. These racks were made of boards $\frac{7}{8}$ x 6 ins. x 8 ft., beveled to a feather edge on the down-stream side, and placed vertically $1\frac{1}{2}$ ins. apart.

The two hook-gauges used, one of the Emerson and one of the Sawyer pattern, read by vernier to 0.001 ft., and the nearest, 0.0005 ft., could be estimated readily. They were placed in two recesses in the walls, one on either side of the basin. Each gauge was securely screwed to a block 20 x 6 x 2 ins., which in turn was firmly fastened to the masonry wall by two $\frac{1}{2}$-in. bolts. The recesses are large enough for a man to sit in comfortably in order to take the gauge readings. In one is an electric bell which strikes every minute or half minute, according as the clock may be set with which it is connected. This recess is also connected by a speaking tube with the room in which the gates are regulated.

The heads (H) were measured in metal pails which were connected with the tail-race in the following way: Six feet back of each weir, parallel to it, and 1 ft. above the bottom of the tail-race, there was placed horizontally a 2-in. brass pipe, the under side of which was perforated with a row of holes $\frac{1}{8}$-in. in diameter, 2 ins. apart. At one end, this pipe was connected by a quarter-bend to a straight pipe leading along the wall of the tail-race to the hook-gauge recess. This latter pipe was connected by a piece of rubber hose to the bottom of the hook-gauge pail, thus allowing the pail to be raised or lowered, so as to keep the water surface always near the top of the pail. The pails were hung on special racks fastened to the wall. This arrangement added materially to the convenience and accuracy of observation. Before the experiments were begun, steam was blown through these pipes, to clean out any dirt that might have collected in them.

With the sills set at $l = 4$ ft., the first stream of water was let into the tail-race. The wicket in the dam of the trapezoidal weir was left open so that both basins could fill at the same time, thus relieving the pressure on this dam. When the basins were nearly full, the wicket was lowered and the water was soon pouring over the trapezoidal weir with a head of about $\frac{9}{10}$ ft. The effect which this vein produced upon the water in the lower basin was anything but pleasing. The stilling rack seemed to have only a slight effect upon the stream; the water boiled up as from a small cataract; whirlpools and eddies were to be

found everywhere in the lower basin, and back currents could be plainly seen within 2 or 3 ft. of the ends of the rectangular weir. Before any experiments could be made it was necessary to break the force acquired by this vein from a free fall of nearly 2 ft. to the surface of the water in the lower basin.

First of all, narrow strips were nailed across the backs of the vertical pieces of the stilling rack, making a sort of sieve of it with meshes about 1½ ins. square. This did not have the desired effect, although there was a slight change for the better. The next remedy tried was placing slats 3 ins. x $\frac{7}{8}$ in. x 6 ft. parallel to the axis of the basin from just below the sill of the trapezoidal weir to the top of the stilling rack in front (Page 16). These slats were set edgewise, about 3 ins. apart, with one corner uppermost, so that their sides made an angle of about 45° with the horizontal, sloping each way from the center of the weir, so as to break up the vein and throw the water toward the sides of the canal. They were placed far enough below the sill (0.6 ft.) not to interfere with the discharge. Quite a marked effect was produced in this way; but, as yet, the condition of the water in the lower basin was not satisfactory with heads over $\frac{5}{10}$ ft. Upon the suggestion of Mr. A. F. Sickman, hydraulic engineer for the Water Power Company, the space between the dam and the stilling rack was filled with brushwood, and boards were placed against the up-stream face of the rack so as to extend across the basin, and from a few inches above the water surface to 1 ft. or 1½ ft. below it. All these devices, together with a floating rack, a few feet from the down-stream side of the vertical stilling rack, produced the desired effect, a perfectly smooth surface and hardly any velocity of approach, for heads up to about 1 ft.

The floating rack consisted of two 3 x 12-in. planks, about 3 ft. apart, extending across the basin, parallel to the weir and held in position by ropes.

The water approaching the trapezoidal weir, throughout the experiments was uniformly in perfect condition, without the slightest sign of an eddy or cross-current. This excellent result was due to the large area of cross-section of the canal of approach (the width being 20 ft. and the depth below the crest of the weir nearly 8 ft.), and to the method of admitting the water (described above). Some annoyance was experienced at first from the leaking of the timber dam in

which the trapezoidal weir was set. When the two basins were filled with water, an additional load of about 155 tons was brought upon the foundation, and caused a slight temporary settlement, owing to the fact that the flume rested on piles driven into soil infested with quicksands. When the water was removed, the floor returned to its former level. This action caused some of the joints of the dam to open a little, especially the one between the bottom timber and the next timber above ; the bottom timber, being cemented to the floor, rose and sank with it. To overcome this difficulty, the timbers were more securely bolted and nailed together and to the center post in front, and the joints were carefully puttied. But, although these helped, they were not a sufficient remedy, because they had to be applied when there was no water in the basins, and then the joints were tight. Something must be applied which would take up the slight motion caused by the settlement of the floor. Finally, Mr. Sickman proposed, as a cheap and probably effective expedient, that strips of enamel cloth, such as is used for covering table tops, be tacked over the joints on the up-stream face of the dam in such a way as to allow for the vertical movement and yet be water-tight along their edges. This plan proved completely successful, and after the application of the enamel cloth there was no noticeable leak from the upper basin.

The Experiments.—In all, 39 tests were made, ranging from a head of 0.3 ft. on a 3-ft. sill to a head of 1.25 ft. on a 9-ft. sill. Lack of time and the limitations of the apparatus prevented us from further extending the scope of our experiments. The results of the first seven tests cannot be used, because, as was discovered during the seventh, the temporary dam still leaked; hence the data from these were thrown out, since, owing to the arrangement of the water passages from the wheel pit to the tail-race, this leakage could not be measured. At the close of the seventh experiment, the enamel cloth was applied to the dam, as mentioned above, and during the remaining 32 experiments, there was no leak through this dam.

With a few exceptions, the duration of an experiment was ten minutes, eleven readings of each hook-gauge being taken. One observer, throughout the experiments, took the heads upon the rectangular weir with the Emerson gauge; the other observed the heights on the trapezoidal weir with the Sawyer gauge. The electric bell was set to

strike once a minute. In each experiment, the water was allowed to run until it was ascertained by taking several readings of the gauges that the flow was quite steady. Then, at a given signal, we began to record the gauge readings at each ringing of the bell. By means of the excellent arrangement of gates, the depth of water on the sills of the weirs could be very closely adjusted and well controlled. Only at certain hours of the day, when the large mills were starting up or shutting down, was any trouble experienced in maintaining a reasonably constant head.

In studying the records of the gauge readings, it was noticed, in the cases of some experiments, that by omitting one or two readings at the beginning, or at the end, or both, a consecutive list of heads could be obtained which had a much smaller extreme variation than was given by the whole eleven readings. Examination showed that the greater variations in the cases of the rejected readings, as well as in some other experiments, were probably caused, in most instances, by the sudden shutting off or letting on of water at the wheels of the electric street railway company, whose power-house adjoins the testing flume. At or near the quarter hours, all the cars of the system were stopped for a half minute or so at certain transfer stations. These sudden and extreme changes in the load on the wheels at the central power station of course made corresponding fluctuations in the amount of water drawn by the wheels from the canal, and this, in turn, slightly affected the level of the water in the canal near the entrance to the flume. There were seven experiments altogether from which one or two or three readings of H have been rejected. In five of these, the rejected readings occurred at or very near the quarter hour. In five cases, to have retained the full set of readings would have given a greater extreme variation in H than that in Experiment No. 20. For the trapezoidal weir, in experiment 23, the extreme variation would have been 0.0450 instead of 0.0060; in experiment 39, 0.0210 instead of 0.0170. For the rectangular weir, in experiment 10, the extreme variation would have been 0.0240 instead of 0.0030; in experiment 23, 0.0350 instead of 0.0060; and in experiment 39, 0.0215 instead of 0.0155.

In a few other experiments, although the extreme variation in H was above the average, the erratic readings could not be discarded without breaking the continuity of the set. These variations in H for the trapezoidal weir are given in column 14 of Table No. 2, and for the

rectangular weir, in column 5. The largest variation given by column 5 is 0.019 ft. in experiment 20. In the majority of cases, the variation does not exceed 0.008 ft. In column 14, the greatest variation of H is shown to be 0.02 ft.; also in experiment 20, while a large majority do not exceed 0.006 ft. These results are well within the limits of the experiments made by Mr. Francis at the lower locks, in Lowell, Mass., in 1852, his greatest variation in head during an experiment being 0.0315 ft. Of course when a value of H for the trapezoidal weir was rejected, the corresponding valve of H for the rectangular weir was also rejected.

To illustrate the above remarks, a few pages from the note book are reproduced. The time given is that recorded by the observer's watches; it may have varied slightly from that of the street railway people.

Experiment 9.—April 13th, 1893. $l = 4$ ft. Head on trapezoidal weir:

7.20	P.M.,	0.9605 ft.	
7.21	"	0.9575 "	
7.22	"	0.9580 "	Extreme variation in 11 readings, 0.008 ft.
7.23	"	0.9600 "	Arithmetical mean value of H.... 0.9603 "
7.24	"	0.9610 "	Mean H by Francis formula..... 0.9602 "*
7.25	"	0.9615 "	
7.26	"	0.9605 "	
7.27	"	0.9605 "	
7.28	"	0.9635 "	
7.29	"	0.9655 "	
7.30	"	0.9650 "	

Experiment 11.—April 13th, 1893. $l = 4$ ft. Head on trapezoidal weir:

8.19	P.M.	0.4510 ft.	
8.20	"	0.4535 "	
8.21	"	0.4500 "	Extreme variation in 11 readings, 0.0110 ft.
8.22	"	0.4515 "	Extreme variation in first 8 readings..... 0.0035 ft.
8.23	"	0.4515 "	Arithmetical mean value of H.... 0.4515 "
8.24	"	0.4510 "	
8.25	"	0.4500 "	
8.26	"	0.4535 "	
8.27	"	0.4435 " ? †	
8.28	"	0.4425 " ?	
8.29	"	0.4425 " ?	

* See Page 26.

† Readings marked ? were omitted in reducing the data of the experiment.

Experiment 18.—April 14th, 1893. $l = 4.982$ ft. Head on trapezoidal weir:

11.53	A.M.	0.2385 ft.	
11.54	"	0.2390 "	
11.55	"	0.2395 "	Extreme variation in 11 readings, 0.0060 ft.
11.56	"	0.2410 "	Arithmetical mean value of H.... 0.2390 "
11.57	"	0.2405 "	Mean H by Francis formula..... 0.2391 "
11.58	"	0.2410 "	
11.59	"	0.2405 "	
12.00	M.	0.2390 "	
12.01	P.M.	0.2380 "	
12.02	"	0.2365 "	
12.03	"	0.2350 "	

Experiment 20.—April 14th, 1893. $l = 4.982$ ft. Head on trapezoidal weir:

2.35	P.M.	0.6880 ft.	
2.36	"	0.6885 "	
2.37	"	0.6735 "	Extreme variation in 16 readings, 0.0200 ft.
2.38	"	0.6795 "	Arithmetical mean value of H.... 0.6817 "
2.39	"	0.6835 "	Mean H by Francis formula.... 0.6817 "
2.40	"	0.6935 "	
2.41	"	0.6835 "	
2.42	"	0.6735 "	
2.43	"	0.6820 "	
2.44	"	0.6770 "	
2.45	"	0.6930 "	
2.46	"	0.6835 "	
2.47	"	0.6750 "	
2.48	"	0.6820 "	
2.49	"	0.6765 "	
2.50	"	0.6740 "	

Experiment 22.—April 14th, 1893. $l = 4.982$ ft. Head on trapezoidal weir:

4.09	P.M.	1.1415 ft.	
4.10	"	1.1415 "	
4.11	"	1.1415 "	Extreme variation in 11 readings, 0.0035 ft.
4.12	"	1.1435 "	Arithmetical mean value of H.... 1.1423 ft.
4.13	"	1.1430 "	

4.14	P.M.	1.1420 ft.
4.15	"	1.1415 "
4.16	"	1.1445 "
4.17	"	1.1420 "
4.18	"	1.1410 "
4.19	"	1.1430 "

Experiment 23.—April 14th, 1893. $l = 4.982$ ft. Head on trapezoidal weir:

4.34	P.M.	1.3995 ft.	
4.35	"	1.3995 "	
4.36	"	1.4000 "	Extreme variation in 11 readings, 0.0450 ft.
4.37	"	1.4030 "	Extreme variation in first 9 readings..... 0.0060 ft.
4.38	"	1.4035 "	Arithmetical mean value of H..... 1.4021 "
4.39	"	1.4015 "	Mean H by Francis formula ..... 1.4021 "
4.40	"	1.4055 "	
4.41	"	1.4035 "	
4.42	"	1.4025 "	
4.43	"	..... ?	
4.44	"	..... ?	

The notes of experiments 11 and 23 are reproduced as examples of cases in which readings of H were rejected. Number 20 is given because in this experiment the greatest variation in H occurred, and because it represents a few cases to which this method of selection could not be applied for the reason that the head fluctuated continually throughout the course of the experiment. Numbers 9, 18 and 22 represent the majority of the experiments, in which the variations were slight. Number 22 is noteworthy for showing so small a variation with so great a depth on the weir.

Each hook-gauge had an adjustable vernier, and, consequently, could be set to read exactly 0.000 when the point of the hook was at the level of the sill of the weir with which the gauge was connected. An 18-in. engineer's V level and a light rod were used in comparing the heights of the sills with the gauges. Several such comparisons were carefully made during the course of the experiments.

The sill lengths were measured with standard 1, 4, 6 and 8-ft. wooden rods made by Darling, Browne & Sharpe, of Providence, R. I.,

and graduated to hundredths of a foot. These rods were tested by Prof. W. A. Rogers, of Cambridge, and found to be very accurate. In order to insure accuracy in the slope of the ends of the trapezoidal weir, a template of hard wood was carefully made, having sides about 2 ft. long, which could be applied to the angles of the weir. By means of the slots and screws mentioned above, the iron plates forming the ends of the weir could be adjusted so as to fit the template to a nicety.

At the close of the 32d experiment, it was noticed that the middle of the temporary dam for the trapezoidal weir had bulged a little. Measurement showed that the center of the sill (set at $l = 7.952$ ft.) was about $\frac{3}{8}$ in. out of line. This deflection proved to be too small to sensibly affect the measurement of l.

The least distance from the end of the sill to the nearer side of the canal of approach L occurred in series VI when $l = 8.943$ ft., and was about 5.5 ft. Since the greatest head in this series was 0.9478 ft., the condition that L must be at least $2\ H$ was abundantly fulfilled. G for the rectangular weir was 5.8 ft., and the greatest head on it was 1.4056 ft. in experiment 32. G for the trapezoidal weir was 7.8 ft., and the greatest head on it was 1.4021 ft. in experiment 23. Hence the requirement that G must be at least $3\ H$ was fully satisfied.

As the temporary dam was made quite tight, there is no correction for leakage to be made in the discharge over the trapezoidal weir. The leakage from the lower basin was determined by shutting the admission gates completely and then taking three or four readings of the hook-gauge, the first just when the water had entirely ceased to flow over the sill of the rectangular weir, the second about five or six minutes later, and the third at the end of 10 or 12 minutes. It was possible to take these small readings below the level of the sill, because the stem of the hook-gauge was graduated for a short distance above the zero point. From these observations the subsidence of the water in a given time was obtained, and knowing the net area of the horizontal cross-section of the basin, the amount discharged in the given time was easily computed. The average was found to be 2.274 cu. ft. per minute, or about 0.038 cu. ft. per second. But this cannot be taken as the rate of leakage during an experiment. Regarding the crevices through which the water escaped as submerged orifices, the discharge through them can be considered as varying nearly in proportion to the square roots of the effective heads upon the orifices, *i. e.*, in proportion to the square

roots of the differences between the water levels in the lower basin and the second level canal into which the weir discharged. The crest of the rectangular weir was about 0.8 ft. above the surface of the water in the second level canal, and so the measurements which gave the above rate of discharge, 2.274 cu. ft. per minute, were made when the effective head on the orifices was approximately 0.8 ft. Hence, to obtain the correction for leakage (M) for any experiment the following formula has been used:

$$M = \frac{2.274\, t\, (h + 0.8)^{\frac{1}{2}}}{\sqrt{0.8}}$$

t being the time in minutes.

The numerical results of 32 experiments are embodied in the table on the folded inset sheet. All quantities are expressed in English units. Some of the columns call for no remarks besides the statements given in the nomenclature; but others need a word of explanation.

Columns 2 and 11, H, give the mean observed heads on the weirs during the experiment. In those cases in which the extreme variation of the head did not exceed 0.005 ft., the arithmetical mean of the hook-gauge readings was taken as the value of H for that experiment. In other cases, the mean head was determined by the use of the formula given by Mr. J. B. Francis, on page 112, Article 150, "Lowell Hydraulic Experiments." It is deduced as follows:

It is very nearly accurate to say that—

$$q = \frac{t'}{2} C l H_1^{\frac{3}{2}} + \frac{t' + t''}{2} C l H_2^{\frac{3}{2}} + \frac{t'' + t'''}{2} C l H_3^{\frac{3}{2}} + \ldots + \frac{t^n}{2} C l H_n^{\frac{3}{2}}$$

$$= C l \left(\frac{t'}{2} H_1^{\frac{3}{2}} + \frac{t' + t''}{2} H_2^{\frac{3}{2}} + \frac{t'' + t'''}{2} H_3^{\frac{3}{2}} + \ldots + \frac{t^n}{2} H_n^{\frac{3}{2}} \right)$$

also $q = T\, C\, l\, H^{\frac{3}{2}}$, approximately. Whence—

$$H = \left(\frac{\frac{t'}{2} H_1^{\frac{3}{2}} + \frac{t' + t''}{2} H_2^{\frac{3}{2}} + \frac{t'' + t'''}{2} H_3^{\frac{3}{2}} + \ldots + \frac{t^n}{2} H_n^{\frac{3}{2}}}{T} \right)^{\frac{2}{3}}$$

in which $H_1, H_2, \ldots H_n$ are the observed heads, the arithmetical means being taken of readings varying by not more than 0.002 ft. $t', t'', t''' \ldots t^n$ are the corresponding intervals of time.

$$T = t' + t'' + t''' + \ldots + t^n.$$

TABLE No. 2.

FRANCIS WEIR.—$q = t\,\frac{10}{3}\,(l - 0.2\,h)\,h^{\frac{3}{2}}$

CIPPOLETTI WEIR.—$C = \frac{Q}{l\,h^{\frac{3}{2}}}$

SMITH FORMULA.—$q_1 = t\,c\,\frac{8}{3}\sqrt{2\,g}\;l\,h^{\frac{3}{2}}$

Series and No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	t	H	h_a	h	$e.v.h.$	l	q	M	q'	Q	H	h_a	h	$e.v.h.$	l	C	c'	Per Cent. of Error.
I—8	600	1.1731[1]	0.0002	1.1734	0.0056	4.000	9571.933	36.722	9607.855	16.013	1.1483	0.0001	1.1486	0.0046	4.000	3.253	.608	3.89
9	600	0.9790[2]	0.0001	0.9792	0.0056	4.000	7372.256	33.904	7406.160	12.344	0.9612[2]	0.0001	0.9613	0.0080	4.000	3.274	.612	2.76
10	420	0.8027	0.0001	0.8028	0.0030	4.000	3866.357	22.531	3888.888	9.259	0.7863	.....	0.7862	0.0050	4.000	3.321	.621	1.37
11	420	0.4584	.....	0.4584	0.0020	4.000	1698.180	15.904	1718.144	4.091	0.4515	.....	0.4515	0.0035	4.000	3.371	.630	+ 0.12
12	600	0.3538[3]	.....	0.3538	0.0055	4.000	1653.756	27.910	1681.666	2.802	0.3475	.....	0.3475	0.0050	4.000	3.420	.639	+ 1.57
13	600	0.2653	.....	0.2653	0.0045	4.000	1078.678	25.241	1104.917	1.841	0.2600	.....	0.2600	0.0060	4.000	3.472	.649	+ 3.12
II—14	600	0.6114[5]	.....	0.6114	0.0080	4.000	2850.778	39.123	2879.901	4.800	0.5780[5]	.....	0.5780	0.0065	5.990	3.448	.645	+ 2.41
15	600	0.2489	.....	0.2489	0.0026	4.000	981.041	26.058	1007.079	1.678	0.1937	.....	0.1937	0.0026	5.980	3.292	.616	1.96
16	600	0.7094[3]	.....	0.7094	0.0075	4.000	4610.416	31.236	4641.850	7.736	0.6396	.....	0.6396	0.0035	5.980	3.264	.610	3.06
17	600	1.0218[5]	0.0002	1.0221	0.0070	4.000	7344.236	34.319	7378.555	13.131	0.7723	0.0001	0.7724	0.0020	5.980	3.258	.605	3.92
III—18	600	0.2730	.....	0.2730	0.0075	4.000	1125.552	26.336	1151.888	1.920	0.2391[3]	.....	0.2391	0.0060	4.982	3.296	.617	2.11
19	600	0.5395[3]	.....	0.5396	0.0105	4.000	3084.780	29.426	3114.206	5.190	0.4648[3]	.....	0.4648	0.0135	4.982	3.287	.616	2.38
20	900	0.7932[6]	.....	0.7932	0.0190	4.000	8141.132	48.136	8189.268	9.099	0.6817[6]	.....	0.6817	0.0200	4.982	3.245	.607	3.62
21	600	0.9983[5]	0.0001	0.9985	0.0085	4.000	7583.566	34.096	7617.665	12.696	0.8401	0.0001	0.8401	0.0025	4.982	3.257	.609	5.27
22	600	1.0056	0.0003	1.0060	0.0045	6.000	11702.136	34.167	11736.502	19.561	1.1423	0.0002	1.1426	0.0035	4.982	3.215	.601	4.51
23	480	1.2340[3]	0.0006	1.2348	0.0060	6.000	12830.215	29.013	12859.228	26.373	1.4021[3]	0.0003	1.4026	0.0060	4.982	3.187	.596	5.36
IV—24	420	0.3811	.....	0.3811	0.0030	6.000	1951.140	19.341	1970.481	4.692	0.3493	.....	0.3493	0.0046	6.963	3.284	.611	3.06
25	600	0.7029	.....	0.7029	0.0020	6.000	6905.952	31.168	6937.120	11.562	0.6392	.....	0.6392	0.0015	6.963	3.249	.608	3.50
26	600	0.9238	0.0003	0.9240	0.0030	6.000	10329.714	33.382	10363.096	17.272	0.8379	0.0009	0.8381	0.0020	6.963	3.233	.605	3.98
27	600	1.1919	0.0005	1.1926	0.0036	6.000	16907.474	35.889	16943.365	26.072	1.0714	0.0003	1.0719	0.0050	6.963	3.245	.607	3.62
IV—28	600	0.2554[5]	.....	0.2554	0.0085	6.000	1535.675	26.119	1561.794	2.603	0.2363[5]	.....	0.2363	0.0060	6.963	3.255	.609	5.53
V—29	600	0.3679[5]	.....	0.3679	0.0070	6.000	2644.946	27.478	2672.424	4.454	0.3089[5]	.....	0.3089	0.0060	7.952	3.263	.610	3.09
30	600	0.6503[5]	.....	0.8503	0.0060	6.000	6156.465	30.618	6187.083	10.312	0.5425	.....	0.5425	0.0045	7.952	3.245	.607	3.62
31	600	1.0868	0.0004	1.0874	0.0045	6.000	13113.879	34.923	13148.802	21.915	0.8924	0.0003	0.8928	0.0045	7.952	3.267	.611	2.97
32	600	1.4069[5]	0.0008	1.4070	0.0056	6.000	19069.022	27.766	19123.788	31.876	1.1518	0.0006	1.1525	0.0050	7.952	3.243	.606	3.68
VI—33	480	0.6565[5]	.....	0.6565	0.0180	6.000	4983.529	24.636	5008.064	10.434	0.4971[4]	.....	0.4971	0.0090	8.943	3.229	.623	1.15
34	600	0.3863	.....	0.3863	0.0050	6.000	2844.019	27.691	2871.704	4.786	0.2940	.....	0.2940	0.0040	8.943	3.357	.628	0.30
35	600	0.9061	0.0003	0.9065	0.0020	6.000	10644.051	33.212	10677.263	16.795	0.6846	0.0002	0.6846	0.0025	8.943	3.315	.620	1.54
36	600	1.2532	0.0006	1.2540	0.0045	6.000	16146.691	36.437	16183.128	26.972	0.9472	0.0004	0.9478	0.0035	8.943	3.269	.611	2.91
VII—37	180	0.7044[3]	.....	0.7044	0.0140	3.000	1014.166	9.356	1023.521	5.686	0.7030	.....	0.7030	0.0030	2.970	3.248	.607	3.55
38	300	0.9639[4]	0.0001	0.9640	0.0120	3.000	2617.569	16.836	2634.445	8.781	0.9436[4]	.....	0.9436	0.0130	2.970	3.226	.603	4.19
39	240	0.3168[4]	.....	0.3168	0.0156	3.000	418.917	10.752	429.667	1.790	0.3276[4]	.....	0.3275	0.0170	2.970	3.216	.601	4.48

Series and No.	19	20	21	22	23	24	25	26	27
	c	q_1	q_1^1	Q'	C'	$c_1{}^1$	Per Cent. of Error.	Temp. Fahr.	REMARKS.
I—8	.595	9705.944	9740.966	18.295	3.298	.617	2.06	Air, 46°	
9	.599	7448.270	7482.174	12.470	3.308	.619	1.75	Water, 39.6°	
10	.802	3889.786	3912.317	9.316	3.342	.625	0.74		
11	.612	1705.291	1726.195	4.110	3.387	.633	+ 0.60		
12	.618	1668.958	1696.268	2.827	3.450	.645	+ 2.46		
13	.624	1094.299	1120.480	1.867	3.521	.658	+ 4.57		
II—14	.610	2862.703	2891.826	4.920	3.463	.648	+ 3.85		
15	.625	995.992	1021.990	1.703	3.341	.626	0.77	Air, 45°	
16	.604	4631.913	4662.448	7.771	3.278	.613	2.64	Water, 39.5°	
III—18	.628	1140.393	1166.729	1.945	3.339	.624	0.83		
19	.609	3096.886	3126.311	5.211	3.301	.617	1.96		
20	.602	8186.226	8234.362	9.149	3.263	.610	3.09		
21	.598	7656.737	7690.833	12.818	3.288	.615	2.35		
22	.603	11711.866	11746.032	19.677	3.217	.602	4.46		
23	.599	12856.822	12885.835	26.429	3.194	.597	5.14	.....	Water at rectangular weir not very smooth.
IV—24	.618	1959.104	1978.445	4.719	3.278	.613	2.64		
25	.608	6896.952	6926.120	11.547	3.245	.607	3.62		
26	.604	10326.598	10359.977	17.287	3.232	.605	4.01		
27	.599	16916.886	16952.775	26.088	3.247	.607	3.56	.....	do.
28	.627	1537.799	1563.918	2.640	3.301	.617	1.66		
V—29	.618	2654.573	2682.049	4.470	3.274	.612	2.76		
30	.609	6147.521	6178.159	10.297	3.241	.606	3.74		
31	.601	13118.121	13153.044	21.922	3.268	.611	2.94	Air, 46°	
32	.596	19146.982	19184.748	31.975	3.255	.608	3.39	Water, 38°	do.
VI—33	.609	4977.126	5001.861	10.420	3.325	.622	1.25		
34	.617	2851.546	2879.237	4.799	3.368	.630	0.03		
35	.605	10661.227	10684.439	16.807	3.318	.621	1.46		
36	.598	16164.424	16200.861	27.001	3.272	.612	2.82	.....	do.
VII—37	.603	1029.319	1038.674	5.770	3.296	.616	2.11		
38	.596	2672.519	2686.356	8.964	3.293	.616	2.30	.....	Fluctuating head.
39	.618	424.236	434.988	1.819	3.255	.609	3.33		

TABLE No. 1.

Number of Experiments.	Duration. Minute.	Head on Rectangular Weir.		Difference between 3 and 4.	Extreme variation in *H*.	Head on Trapezoidal Weir.		Difference between 7 and 8.	Extreme Variation in *H*.
		Arith. Mean.	Formula.			Arith. Mean.	Formula.		
1	2	3	4	5	6	7	8	9	10
8..	10	1.1732	1.1731	— 0.0001	0.0055				
9..	10	0.9791	0.9790	— 0.0001	0.0055	0.9612	0.9612	.....	0.0080
12..	10	0.3539	0.3538	— 0.0001	0.0055				
14..	10	0.5113	0.5114	+ 0.0001	0.0080	0.3780	0.3780	.....	0.0055
16..	10	0.7094	0.7094	.....	0.0075				
17..	10	1.0216	1.0218	+ 0.0002	0.0070				
18..	10	0.2727	0.2730	+ 0.0003	0.0075	0.2390	0.2391	+ 0.0001	0.0060
19..	10	0.5397	0.5395	— 0.0002	0.0105	0.4650	0.4648	— 0.0002	0.0135
20..	15	0.7928	0.7932	+ 0.0004	0.0190	0.6817	0.6817	.....	0.0200
21..	10	0.9982	0.9983	+ 0.0001	0.0085				
23..	8	1.2341	1.2340	— 0.0001	0.0060	1.4021	1.4021	.....	0.0060
28..	10	0.2554	0.2554	.....	0.0085	0.2363	0.2363	.....	0.0090
29..	10	0.3677	0.3679	+ 0.0002	0.0070	0.3087	0.3089	+ 0.0002	0.0060
30..	10	0.6505	0.6503	— 0.0002	0.0060				
32..	10	1.4056	1.4059	+ 0.0003	0.0065				
33..	8	0.6549	0.6555	+ 0.0006	0.0180	0.4971	0.4971	.....	0.0090
37..	3	0.7039	0.7044	+ 0.0005	0.0100				
38..	5	0.9542	0.9539	— 0.0003	0.0120	0.9439	0.9436	— 0.0003	0.0150
39..	4	0.3169	0.3168	— 0.0001	0.0155	0.3277	0.3275	— 0.0002	0.0170

The small figures to the right and above the values of H in these columns show the number of combinations of readings, used in finding the mean, *i. e.*, they give the values of the subscript n in the above formula.

The above Table No. 1 compares the mean values of H as obtained by the use of the formula with the arithmetical means. The results in columns 5 and 9 would seem to show that the error arising from taking an arithmetical mean of the readings of the hook-gauge instead of deducing the mean value of H by the more correct method depends not so much upon the range of the variations of the readings, as upon the relation of each reading to the arithmetical mean—the grouping, so to speak, of the readings about the arithmetical mean as a center of gravity. In any case, the difference is too small to be worth taking account of in the ordinary use of the weir, and seems equally liable to be positive or negative. Hence, in a series of measurements, these errors would tend to balance one another. It is concluded from this, therefore,

that in the great majority of cases, it is safe to take the arithmetical mean of the hook-gauge readings as the value of the head.

Columns 3 and 12, h_a, give the values of the heads corresponding to the velocities of approach. These values were obtained by use of the formula :

$$h_a = 0.01555 \left(\frac{Q_1}{A}\right)^2,$$

in which Q_1 is the approximate value of the discharge given by the formula :

$$Q_1 = \frac{10}{3} l H^{\frac{3}{2}}.$$

Columns 4 and 13, h, give the values of the effective heads on the weirs. In correcting for velocity of approach, Mr. Hamilton Smith, Jr.'s, method has been followed, employing his formula for weirs with complete contractions :

$$h = H + 1.4\ h_a.$$

Columns 5 and 14 give the extreme variation in H during an experiment, *i. e.*, the difference between the lowest and the highest reading of the hook-gauge.

Columns 7, 9, 10, 16, 17 and 18 were computed from the results obtained by substituting in the formula :

$$q = t \frac{10}{3} (l - 0.2\ h)\ h^{\frac{3}{2}},$$

in which 0.623 is taken as the value of the coefficient of contraction.

Columns 20, 21, 22, 23, 24 and 25 were computed from the results obtained by the use of the formula :

$$q_1 = t\ c\ \tfrac{2}{3}\sqrt{2\,g}\ l\ h\ = 5.347\ t\ c\ l\ h^{\frac{3}{2}}.$$

Column 19 gives the values of c used in the above formula. These values were obtained by interpolating in Table No. 48, page 132, Hamilton Smith, Jr.'s, "Hydraulics."

Columns 18 and 25 show the percentage of variation of the coefficient for the trapezoidal weir, as deduced from the data of the experiments, from $3.36\frac{2}{3}$, the coefficient deduced by Cippoletti's mathematical research.

$$\text{Per cent. of error} = 3.3\ \tfrac{2}{3} \sim C \div .03367.$$

Conclusions.

The experiments would have been much more satisfactory if the discharge from the trapezoidal weir could have been measured by direct cubic measurements. Nevertheless, the writers believe that they can fairly say that their work was done with sufficient care, and the apparatus used was accurate enough to give results of some practical value.

The discharge of the rectangular weir has been computed in two ways; first, by using the Francis formula—

$$q = t\,\tfrac{10}{3}\,(l - 0.2\,h)\,h^{\frac{3}{2}},$$

in which the coefficient of contraction has the constant value 0.623, the value assumed by Cippoletti in deducing his coefficient; second, by employing the formula—

$$q = t\,c\,\tfrac{2}{3}\,\sqrt{2g}\,l\,h^{\frac{3}{2}},$$

which for this locality becomes—

$$q = 5.347\,t\,c\,l\,h^{\frac{3}{2}},$$

the values of c being taken from the table compiled by Mr. Hamilton Smith, Jr. The values of C computed from either set of figures, with a few exceptions in each case, indicated by plus signs in columns 18 and 25, fall below $3.36\frac{2}{3}$.

Why these four experiments, Nos. 11 to 14 inclusive, should give values of C greater than the theoretical value, while all the others give results which fall below the theory, the writers are at a loss to explain. These experiments were made with same care as the others, and no peculiar conditions were designedly introduced, nor were there any accidental causes of error in these, as far as observed, different from those in the others. These four experiments were made at the close of the evening's work on April 13th, but the fact of their having been made in the evening does not of itself seem a sufficient reason for the peculiarity of their results, for Nos. 9 and 10 and Nos. 25 to 30, inclusive, were also made in the evening, and their results exhibit no such departure from the majority.

The results of the Smith formula vary less from Cippoletti's assumed value of C, but differ a little more from their own average than do those given by the Francis formula. In studying the percentages of error in columns 18 and 25, to discover if there were any law gov-

erning their variation, it was found that (with five or six exceptions) in each series, as the heads increased, the per cent. of negative variation of C, from $3.36\frac{2}{3}$ also increased. This seems to indicate that the increase of the area of the vein due to the inclination of the sides of the weir is not quite sufficient to compensate for the effects of the end contractions; for, if the discharge through the added triangles were just equal to the diminution of the total discharge due to the effects of end contraction, and if the rectangular weir, by using the Francis formula, would give the discharge with an error not greater than 1%, we should naturally expect that the variations in the error would not follow the changes in the head, but that the coefficient would be as likely to show a positive as a negative error (due to inaccuracies in experimentation) and would depart in either direction but 1 or 2% from the value theoretically deduced from the Francis coefficient. However, the writers feel somewhat reluctant about drawing any such conclusion from the few experiments which they had opportunity to make, and the more so because they were unable to measure the discharge directly, but were obliged to determine it by the aid of the rectangular weir.

It may be, however, that the explanation of this connection between the error and the head is to be sought in the arrangement of the apparatus. That is to say, the water, as it approached the rectangular weir, may have had a greater velocity due to its fall from the trapezoidal weir than was suspected, and it may be that there should be a greater allowance made in the discharge on this account than the usual correction for velocity of approach. On this point, all that can be said with assurance from actual observation is, that the surface of the water was smooth, and that chips or other light surface floats showed only a very slight velocity, excepting in the cases where it is noted to the contrary. Of course, the greater the head, the larger would be the quantity of water falling, and, consequently, the greater the difficulty in overcoming the velocity due to its fall from the Cippoletti weir. Hence, possibly, the increasing error with the increase of head.

Results given by the formulas, making a reasonable allowance for inaccuracies of observation in careful work, are generally considered to be liable to an error of about 1%, *i. e.*, the discharge may as truthfully be said to be either $q + 0.01q$ or $q - 0.01q$ as to be called q. Now, in these experiments, since the water was given an initial velocity by its fall from the trapezoidal weir, and since it is probable that this

velocity was not entirely overcome before the water reached the rectangular weir (although the surface was made quite smooth by the devices used), it seems fair to assume that the balance of error was in favor of increasing the discharge. The average value of C in column 16 is 3.283. Making the correction in q by adding $0.01q$, the value of C becomes 3.316, which varies from $3.36\frac{2}{3}$ by 1.51 per cent. But a few of the experiments should not have equal weight with the others. In Nos. 22, 23, 27, 32 and 36, the surface of the water was noticeably agitated as it approached the rectangular weir; and in experiments 37, 38 and 39 the head fluctuated rapidly, because these tests were made at noon time on Saturday, when many of the large mills were shutting down. Omitting these, the average value of C in column 16 becomes 3.301; and, making the correction in q, as above, C now becomes 3.334, which differs from $3.36\frac{2}{3}$ by 0.98 per cent.

Considering the results given by Smith's formula, the average value of C' is found in column 23 to be 3.304. Correcting q_1 in the same way as q above, C' becomes 3.337, which varies from $3.36\frac{2}{3}$ by 0.030 or 0.89 per cent. Omitting numbers 22, 23, 27, 32, 36, 37, 38 and 39, as before, the average value of C' is found to be 3.321; and increasing q_1 for the remaining experiments by 1%, as before, C' becomes 3.354, which differs from $3.36\frac{2}{3}$ by 0.013, or 0.39 per cent.

Therefore, the writers think it fair to conclude from these results that Cippoletti's formula, $Q = C\,l\,h^{\frac{3}{2}}$, when applied to a properly constructed trapezoidal weir, will give the discharge with an error, due to the combined inaccuracies, not greater than one per cent.

Cippoletti's object was to determine a form of weir and a formula which should measure the discharge with an error arising from any one disturbing cause not greater than ½ of one per cent. In order to attain to this standard, the weir must satisfy the following requirements, in addition to those usual for all weirs:

"There must be complete contraction at each end and on the bottom.

"The velocity of approach must be small, not exceeding 0.5 ft. per second for weirs 1 m. (39.37 ins.) long, with a head 1 ft., or 0.66 ft. for weirs 2 m. long, with a head of 2 ft. The cross-section of the canal of approach should be at least seven times that of the vein of water in the plane of the weir.

"The inaccuracy in the measurement of the head should not exceed one-third of one per cent.

"The weir should not vary more than 4° from being perpendicular to the canal of approach.

"The sill must be horizontal." *

The principal advantage claimed for the trapezoidal weir is that the computations are much simpler than for any other form of weir. Anybody who can read a simple gauge and can multiply can use this weir after it has been properly installed, for if a table be compiled giving the discharge over a 1-ft. sill, with various heads, the discharge for any sill length can be obtained by multiplying the number in the table under the given head by the length of the given sill. This obtains because of the automatic elimination of the effect of end contraction, making the discharge for any given head vary directly as the sill length, which the writers have found to be nearly true experimentally, as can be readily deduced from the table.

There are no two experiments in the set between which a direct comparison of the effects of a variation in l alone can be made, for it was not practicable to get the head on the weir exactly the same in two experiments. However, there are two or three cases in which the variation in h is small. According to the formula, $\frac{Q_1}{Q_2} = \frac{l_1 h_1^{\frac{3}{2}}}{l_2 h_2^{\frac{3}{2}}}$.

Comparing experiments Nos. 12 and 24, we find a difference of only 0.0018 ft. in the head. Substituting in the above expression, we have $2.827 \div 4.712 = 0.60$ and $(4.000 \times 0.3475^{\frac{3}{2}}) \div (6.963 \times 0.3493^{\frac{3}{2}}) = 0.57$. But from column 25, we see that the results of No. 12 have a positive variation from the theoretical coefficient of 2.46%, while the results of No. 24 have a negative variation of 2.64 per cent. Comparing in a similar manner experiments Nos. 18 and 28, where the difference in head is 0.0028 ft., we have $1.945 \div 2.640 = 0.74$, and $(4.982 \times 0.2391^{\frac{3}{2}}) \div (6.963 \times 0.2363^{\frac{3}{2}}) = 0.73$. Here, the respective errors in column 25 are 0.83% and 1.96%, both negative.

According to the formula, Q should vary, also, directly as $h^{\frac{3}{2}}$. The experimental results fulfill this requirement very nearly. Comparing Nos. 15 and 17, we have $1.703 \div 13.274 = 0.128$, and $0.1937^{\frac{3}{2}} \div 0.7724^{\frac{3}{2}} = 0.126$. Likewise in Nos. 18 and 21, we have $1.945 \div 12.818 = 0.152$, and $0.2391^{\frac{3}{2}} \div 0.8491^{\frac{3}{2}} = 0.149$. A number of other similar comparisons show equally good or better results.

The trapezoidal weir can be used as a divisor, therefore, and is

* From "Canale Villoresi," etc.

especially adapted to use on irrigation canals. For about 10 years it has been employed in Italy, and has given general satisfaction. One of the chief objections to all measuring devices used on irrigating systems has been their unfairness in that their inaccuracies favored the users of the larger quantities of water. Cippoletti has overcome this, it is claimed. The trapezoidal weir, if it favors any one, probably favors slightly the consumers of the smaller quantities of water.

The authors regret that the experiments have so limited a range. However, they respectfully submit the above figures to the engineering profession, trusting that the fruits of these labors may not be entirely without practical value. Some of the deductions may be erroneous, but they have tried to record the results accurately and honestly. Others may make such interpretations for themselves as their experience and judgment may direct.

The authors wish to acknowledge their indebtedness to the Holyoke Water Power Company for the use of its testing flume and the accompanying conveniences; to Mr. A. Frank Sickman, hydraulic engineer of the above company, for valuable suggestions and personal assistance; to Mr. J. M. Goodell, Assoc. Am. Soc. C. E., assistant editor of the *Engineering Record*, and to Prof. L. G. Carpenter, of the State Agricultural College, Fort Collins, Colorado, for information and literature.

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TESTS OF CONDENSATION IN CAST-IRON RADIATORS.

By WILLIAM J. BALDWIN, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

The writer had occasion recently, in connection with his professional work, to make some comparisons as to the relative efficiencies of several of the regular makes of cast-iron radiators now on the market, and ones that are considered good types of direct cast-iron radiators. The results of the experiments hereinafter given were obtained from four of these radiators that were selected as a standard of comparison for a new radiator about to be put on the market. The results of these experiments are given to this Society, as they form valuable data by which an engineer can approximate the amount of condensation likely to take place in the heating apparatus of a building, and also show how near the line of condensation agrees in steam pipes with a line of the difference of temperature between air and steam.

The writer is compelled to omit the name and make of these four types, but as the results run so nearly together he presumes it is not necessary to go further than to say that they are the ordinary well-known types of cast-iron sectional radiators that are so much used at

the present day. All radiators were of 48 sq. ft. of surface, according to their commercial rating, excepting that designated as No. 3, which contains 52 sq. ft. and which, when reduced to the value of 48 sq. ft., gives the dotted line shown and designated as *X—X* (Plate IV).

The method of comparison used was that known as the condensation test, the only one which is of any value in determining the comparative value of radiators, and consisted of taking steam from a boiler at 90 lbs. pressure and conveying it in a 1-in. pipe to a water separator. This water separator was "trapped" in the usual manner with a Nason trap. From the top of the separator a 1-in. pipe led to a reducing pressure regulating valve and from the pressure regulating valve it led into a header of 2 ins. inside diameter. The connection for each radiator was made of ½-in. pipe, taken from the upper side of this header through a short nipple, and thence by another short nipple into the radiator, an angle valve being used at the corner. It is probable that the condensation taking place in the two short nipples and in the valve was carried forward into the radiator; but, the quantity being so small, it has not been considered, as it was the same in each case.

The radiators were placed on platforms 2 ft. above the floor and 36 ins. from center to center. Over each radiator was placed a frame covered with muslin. The muslin in all cases was 6 ins. from the sides and ends of the radiators, and the frames were opened top and bottom. The frames had the same perpendicular height as the radiator, and were raised sufficiently (about 6 ins.) to permit an uninterrupted flow of air to the radiator underneath the lower edge of the frame. This method enclosed each radiator in a cotton box, as it were, and interposed two thicknesses of muslin between opposing sides of radiators, so as to cut off almost entirely the effects of radiation from one radiator to another. The tables on which the radiators were set had an inclination of about 1 in. to the drip end, so that the condensation could easily gravitate to the apparatus for collecting the water.

The apparatus for collecting and measuring the water consisted of a ⅜-in. "tail pipe," on the side of which was a short ordinary water gauge glass. Both above and below the water glass in the tail pipe was a stop valve; the upper valve being for the purpose of shutting off the connection should the gauge glass break, but during the experiments it was always open. The lower valve was simply a tail valve, to control the escape of water. The tail valve was supplied with 1 ft.

of very light rubber hose ($\frac{3}{8}$ in.) which terminated in a paper pail. The water was drawn into the paper pail through the tail valve, but was always kept in sight in the glass and made to agree with a thread around the middle of the glass, both at the commencement and the end of all trials.

On the header before mentioned was arranged a steam-pressure gauge, and in an oil well in the upper side of the same header was fixed a standard thermometer for the purpose of checking errors in the steam-pressure gauge by comparisons with the temperature of the steam. It will be noted that the trials were generally made at 1, 5, 10, 18 and 30 lbs. pressures, but that some of the circles indicating trials are on other lines, notably in the neighborhood of 5 and 10 lbs. Where the greater number of trials are shown, these differences of pressure are the results of corrections made by the thermometer, the pressure gauge being somewhat inaccurate and the pressures likely to fluctuate $\frac{1}{2}$ lb., or thereabouts; as a pressure-regulating valve is only an approximate instrument for work of this kind. At the lower pressures (1 to 5 lbs.) there is very little loss due to the evaporation of the hot water as it falls into the pails, especially as the end of the hose is kept under water as much as possible. At the higher trials, a small percentage of the hot water, when relieved of its pressure, is converted into steam. This is obviated in a great measure, however, by keeping the end of the hose always under water, which can be done as soon as condensation forms in the bottom of the pail and covers the mouth of the hose.

It is well to remark here that the header before spoken of and in which steam at reduced pressures was admitted to the radiators was also drained and kept dry by an automatic steam trap. The positions of the radiators were also changed from time to time, as it was feared that a radiator in one position might be favored over the others.

At the left of the diagram is shown the steam pressure in pounds per square inch at which various trials were made.

The next line, *A—A*, gives the value in British heat-units of each pound weight of steam for the various pressures, and is measured from the left-hand side of the diagram, each of the larger squares having a value of 100 heat-units, the thermal value of a pound weight of steam being less from the higher pressures.

The curved line *B—B* shows the results obtained in the radiator designated as No. 1, and they were made under conditions of very

PLATE IV.
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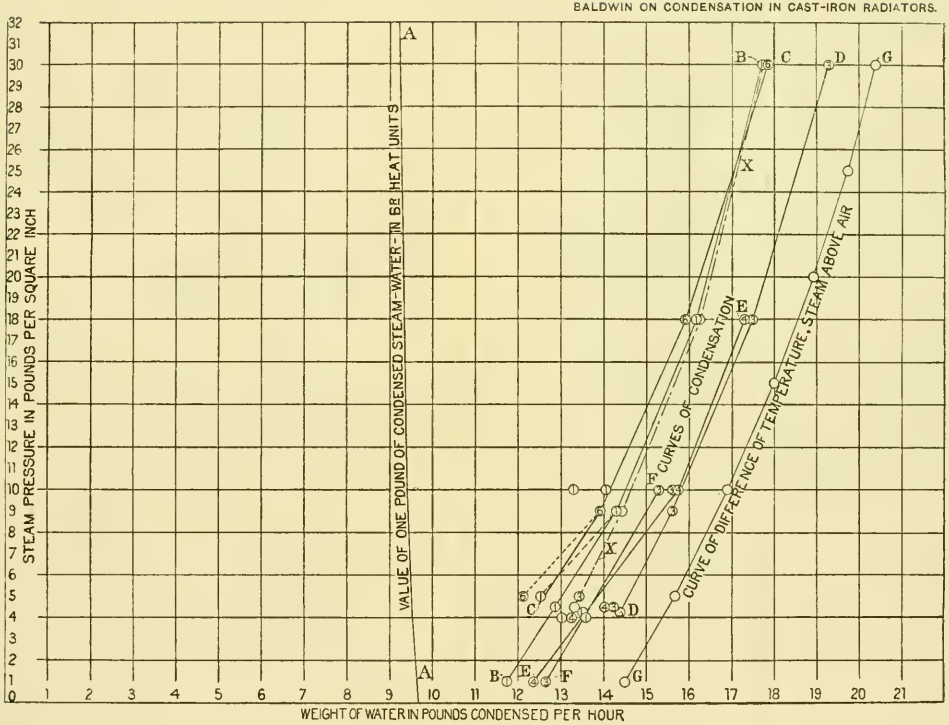

nearly equal temperature, in a room kept constantly between 73 and 74° Fahr.

Line *C—C* shows results obtained for radiator marked No. 6 in the trials, which were made at the same pressures and the same temperatures as the foregoing.

Line *D—D* gives the curve of condensation in the radiator marked No. 3 temperatures and pressures of steam being the same as before.

Line *E—E* shows the results of experiments on radiator No. 4, which at the lower temperatures seems not to do so well. Between the 10-lb. and 18-lb. lines, however, the curve agrees with the remaining curves of condensation.

Line *F—F* shows the other experiments made with radiator No. 3, when the temperature of the room averaged between 77 and 78°. This undoubtedly accounts for the line showing the less condensation on that day. The circles 6, 1 and 3 on the 5-lb. line are also results of the tests made when the temperature of the room was about 78°. Other circles enclosing figures in close proximity to lines, with corresponding figures, show values obtained with the same radiator during other trials and under slightly different conditions of the temperature and humidity. They all harmonize, however, with the curves of their respective radiators and tend to confirm the results.

Line *G—G* is the curve of difference of temperature between the steam and the air, and is drawn for comparison with the curves of condensation as discovered by the trials. The uniformity that exists is remarkable. There is a correction, however, to be made for the higher temperatures in the matter of the curves of condensation. As the temperature of the steam advances, the value of 1 lb. of condensation becomes less, as shown in the line *A—A*, so that curves of efficiency of condensation, based on the actual amount of heat lost from the radiator, and not from the number of pounds of water condensed, would all tend a little to the left as they go upward, bending away from the curve of difference of temperature. It is well known that the condensation does not increase directly as the difference of temperature. These experiments, however, show that it (the difference) is not as great as was surmised, and that for all practical purposes the curve of condensation and the curve of difference of temperature is practically alike for any ranges of temperature and pressures carried in low-pressure steam heating apparatus.

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NOTES ON WIRE ROPE TRAMWAYS.

By A. C. SAVAGE, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

The use of wire ropes for transportation in rough country or upon steep inclines is by no means a novelty, and the various methods in use are familiar to most of us, at least in a general way.

It is more with a view of calling attention to the methods adopted in surmounting obstacles in the construction and operation of these lines than with the idea of imparting any very novel information that these notes have been made.

It has been the writer's fortune for the past seven years to be connected in a greater or less degree with wire rope tramway building, and for the past three years he has been engaged in active construction of lines in the United States and Mexico for the Trenton Iron Company.

It is well known that two systems of wire rope lines are in general use, the single and double rope systems. The former is the older of the two, and probably the better known, and is also divided into two systems, one in which the buckets or carriers are detached from the

rope at the terminals, and the other, more commonly in use, where the buckets are rigidly fastened to and are carried by the rope around the terminal wheels, being loaded and unloaded in transit, in some instances by hand, in others by automatic devices, which are more or less successful, owing to the character of the material to be conveyed.

It is manifest that where the load is attached directly and only to the hauling rope the matter of divergence from a regular grade line is of less consequence than in the cases where the strains upon two sets of ropes are considered, and hence the expenses of construction are lessened. In cases, therefore, of small outputs, these single rope lines have a signal advantage in first cost. When, however, the production approaches the limit of their capacity, and is of necessity regular, the great wear, frequent repairs and constantly recurring stoppages render them objects of unceasing solicitude to all parties concerned, and it has been too frequently the case that buyer and seller seem to have entered into a combination to do each other and themselves all the injury possible by fixing on a plant which was inadequate to the needs of the user, and, by its failure, an injury to the reputation of a really good machine when properly used.

The double rope lines have these advantages, that with proper designing and construction the limit to their capacity is far in advance of the possibilities of single rope lines; that the wear on their component parts by skillful adjustment may be reduced to a minimum, and the cost of repairs made very small; and that under competent management the most excellent results as to regularity of operation may be attained.

The designing of one of these lines is seldom a simple and easy piece of work. The instances where the "standard terminals" can be employed, and the intermediate supports put in at the ideal distances of from 150 to 200 ft. apart, are few and far between.

In most instances the line must be accommodated to peculiarities of the case, which, while not insurmountable, are, nevertheless, frequently perplexing.

The forms these difficulties assume are generally—

First.—A cramped location for one or both terminals.

Second.—Heavy grades into or out of the terminals.

Third.—Intervening summits on the line.

Fourth.—Intervening hollows or chasms of great width.

The first trouble of cramped location is perhaps the ever-present one, especially at the upper terminal in mine tramways.

The steep side hills most suitable for terminals, and offering the greatest facilities for waste dumps, offer but little foothold for the necessary floor space for a tramway terminal. For width with the standard 8-ft. line 20 ft. will do, though 24 ft. is better, but for length 60 ft. is none too much. Room should be left behind the machinery for switches, on which empty cars may stand when not in use.

But it is when this is combined with the second case, that of heavy grades at the upper terminal, that its worst features are manifest. An example of this is the upper terminal of the "Ground Hog" lines, situated on the rim of Silver Bow Basin, near Juneau, Alaska, and recently completed under the supervision of the writer. The only available spot on the whole mountain side was selected.

The outgoing grade is 60%, and it was impracticable to support the line at the immediate foot of the bluff, as the support must have stood directly in the track of a very heavy annual snow slide. The vertical curve of the trestle in front of the terminal has a radius of 200 ft., and over this the rope is carried in saddles on cross-ties 2 ft. apart.

The difficulties with this arrangement are twofold. First, the great strain on the traction rope and bucket frames arising from the transition from the level grade at the attaching point to the 60% grade at the end of the trestle. An inclined terminal would obviate this, and a good deal of study has been given to this point and many expensive experiments made by the engineers of the Trenton Iron Company without achieving satisfactory results, the trouble lying in the difficulty of attaching the loaded bucket to the traction rope on the incline in safety.

In the second place, the sudden deflection of the traction rope from the guide wheel to the first carrying roller is such that attaching can only be done at one point, it being impossible to force the bucket by hand in advance of the lug when once the traction rope has entered the grip. This would also be avoided in the inclined terminal, but, in default of that, a swinging guide wheel has been attached ahead of the attaching point, making the traction rope nearly level for a distance of about 6 ft., which will allow the attachment to be made with ease.

This swinging guide supports the rope about 1 in. lower than does

the wheel on the bucket below the grip, and, as the bucket passes, it is pushed to one side, returning to its position as soon as the load has passed.

In this connection it may be pertinent to speak of the means adopted to get the material to the site of the terminal. The whole face of the mountain was covered with loose slate and shale, making anything resembling a road impossible without great expense; and at the foot of the slope was a chasm, through which a mountain torrent flowed. A little 8-H.P. hoisting engine was carried to the top, and then pulled up the cables.

Stretching these over low temporary supports, a tramway was improvised over which our terminal machinery, timber, buckets, etc., were all carried to the site, the engine being worked by compressed air from a neighboring mine. The permanent supports were then erected, and the cables transferred to their proper positions. The difficulties of this line in a climate where the snow had not entirely disappeared from the side hills in July, and where the rain was almost incessant during the entire season, are easier imagined than described.

Intervening Summits.—These are a fertile source of trouble, particularly in heavily loaded lines, owing to the severe strains put upon the bucket frames by the weight of the traction rope and its load.

It is evident that as each bucket surmounts one of these summits, it necessarily has to sustain temporarily the entire weight due to the loads on either side of it to the foot of the grade. This is to a limited extent remedied by frequent supports so placed as to form an easy vertical curve, that the rollers may catch the weight of the rope as quickly as possible. Heavy wear is also induced in the stationary cables at these points, and it frequently becomes necessary to construct a continuous trestle over the summit, and substitute a solid rail for the standing rope, on which the carriages may travel. Examples of these summit curves are the Guanecori Tramway, Durango, Mexico, and the Benners Bay Tramway, near Seward City, Alaska. Two especial examples are those of the "Bunker Hill and Sullivan" line, at Wardner, Idaho. They are both trestled and furnished with rails, and are snow-shedded for winter protection. The profile (Plate V) shows the construction.

They were originally built with the rails supported on the iron

hangers, secured to 6 x 8-in. hanger timbers in the way ordinarily employed in terminals. It was found, however, that these timbers gave down under the load, and they were re-enforced by 8 x 10-in. timbers placed above them, to which the original timbers were connected by yokes of 2 x ½-in. iron.

Intervening Hollows.—These, when of considerable width, frequently become another annoying feature in tramway building.

The ropes should be supported at either end, in such a way that no sharp angles will occur ; and, generally speaking, it is better that in really long spars the standing ropes should be, as nearly as possible, independent of the rest of the line. This is especially the case when the two extremities of the span are approximately on a level. In such a case a tension station should be put in at the lower, and an anchorage at or not far from the upper, end ; and the size of the ropes should be greater and the tensions higher than for the supported portions of the line.

The writer has found, in his own practice, that, where the conformation of the ground will permit, long spans, properly adjusted, are a positive advantage to a tramway line.

The reasons for this may be summarized as follows :

First, and manifestly.—A more regular grade line is attainable than where the line is broken to suit the conformation of the ground.

Second.—The points of danger of wreckage on these lines occur at the supports, and are due to supports out of line or misplaced saddles, against which the passing carriages may strike. The writer has never known of an accident occurring on a clear span, except through failure of the grip, with which the span has nothing to do.

Third.—The wearing points on the carrying cables are, of course, only at the supports. A reduction in the number of these points is, therefore, manifestly a benefit to the line.

Fourth.—The reduction of the number of supports to be inspected and kept in repair is a reduction in expense of maintenance, and therefore desirable.

In designing these long spans, it becomes necessary to alter the form of support at their termini in many cases, to avoid undue wear upon the stationary cables at these points. The writer has obtained very good results during the past season by attaching two caps instead of one to the top of the towers, and so setting the saddles as to

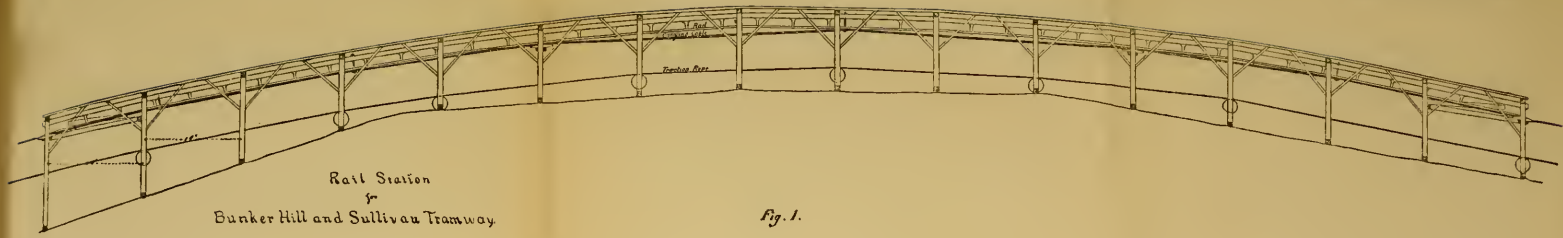
Rail Station
for
Bunker Hill and Sullivan Tramway.

Fig. 1.

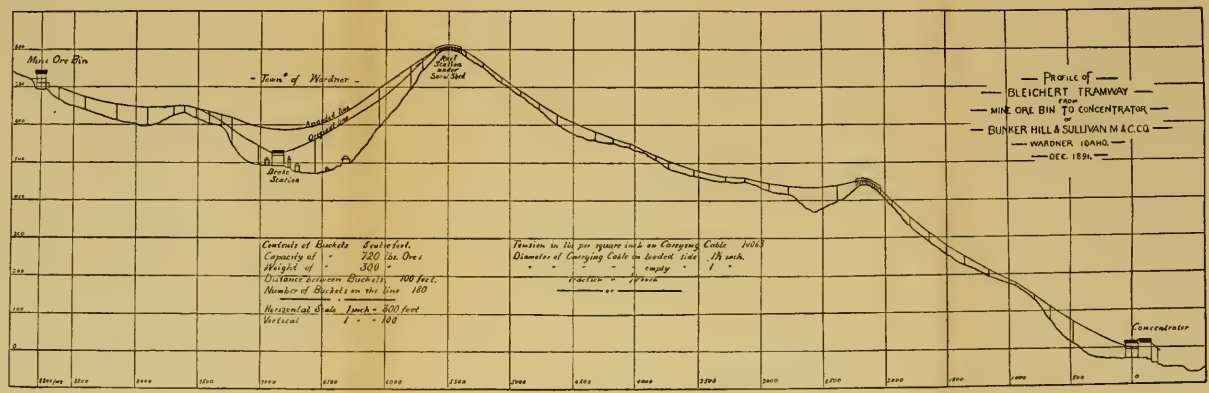
Mine Ore Bin
Town of Wardner
Angle of Inclination
Brake Station
Rail Station under Snow Shed
Profile of
Bleichert Tramway
from
Mine Ore Bin to Concentrator
of
Bunker Hill & Sullivan M. & C. Co.
Wardner Idaho.
Dec. 1894.
Concentrator
Contents of Buckets 1 cubic foot.
Capacity of " 720 lbs. Ore
Weight of " 300 "
Distance between Buckets 100 feet.
Number of Buckets on the line 180
Horizontal Scale 1 inch = 500 feet
Vertical 1 " = 100
Tension in lbs per square inch on Carrying Cable 14063
Diameter of Carrying Cable on loaded side 1 1/8 inch.
" " " " " empty " 1 "
Traction " 7 feet
" "

Fig. 2.

present a supporting arc of some 40 ins. in length. In case of very long spans this could be still further increased in length by the addition of still another cap; but it has been found that the 40-in. arc, with a radius of 5 ft., is ample for spans of 1 500 ft. in length.

In the case of the Bunker Hill and Sullivan line, which for a time seemed to defy any efforts to make it work smoothly, the trouble disappeared when the changes were made which are indicated on the profile. In this case the line had been held down where it crossed Milo Gulch, and the traction rope cut at the lowest point, making practically two lines of it.

In remodeling it, this intermediate station was taken out and a span of 1 180 ft. carried entirely over the gulch. The traction rope was made continuous, and the good effects were at once apparent.

The benefit derived from the long span may be inferred from the fact that on the occasion of the breaking of the main driving shaft at the upper end, and the consequent running away of the line, not a single bucket was dropped from the long span.

This line is furthermore a good example of the capabilities of these lines. Although by no means one of the heaviest in equipment, having only 5 cu. ft. buckets as carriers, it has for a year and a half carried easily its 50 tons per hour and made an average record for months of 450 tons per 10 hours' work, at a cost of about 16 cents per ton, which, taken in connection with the high rate of wages paid in that camp, is certainly very cheap work. This takes into account only the ore delivered, and does not include the return transportation of supplies, timber, etc., which has frequently run up to 30 or 40 tons in a day.

These few notes are submitted in the belief that a more general understanding of the requirements and capabilities of these lines may lead to further improvements in their design. While in no sense competitors with surface transportation for general freight, they might easily be made valuable adjuncts for special products, and in cases where the nature of the country is unfavorable to surface lines.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

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718.

(Vol. XXXII.—July, 1894.)

STEAM AND ELECTRIC CABLEWAYS FOR LOGGING AND CANAL-BOAT TOWING.

By RICHARD LAMB, Assoc. M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

The antiquity of the carry-log that most of our lumber-men are using to-day is undoubted. The writer has, at least, seen exceedingly old illustrations showing big two-wheel carry-logs drawn by oxen, which would serve to show how logs are hauled at the present time.

It is true that during the last 50 years or so narrow-gauge light rail steam railroads have been very generally used in logging, but these have been for main lines to take the place of rivers, and they do not displace altogether the old style carry-logs, for they are still used to bring the logs to the railroads.

Of course, in countries where snow is of sufficient duration to admit of sledding, the carry-log is displaced. As much as 36 000 ft. of white pine has been hauled at one time on a sled by one pair of horses. It is, therefore, evident that sleds are cheaper than wagons for logging.

The principal question that the logging engineer has to consider is, how to cut the trees and get them to convenient points for transportation at the least expense. On firm land, the methods employed are carry-logs with oxen or horses, damming the small streams and driving the logs during freshets, and in northern countries sledding. Water flumes, made of wood, are used to advantage in the West.

The Butters system of one-span steam cableway is also used, but only for a maximum distance of 700 ft. Cableways have been tried with horses for the motive power. The fact that the contour of the ground needs to be practically level has caused all such horse cableways to be abandoned. The mechanical principle which operates against cableways where the logs are hauled by horses is that the direction of the force should be practically in the line of what we might call the axis of the horse passing through the hips.

When the land slopes, making considerable of an angle with the direction of the cable, a resultant force is created which equals the weight of the horse and he ceases to be able to pull the log. Any system of steam or electric cableways should be designed with reference to overcoming this difficulty, by making the line of the pulling cable always parallel with the bearing or main cable.

Necessity has caused a great number of experiments to be made in logging in wet or swampy ground. The Butters system is used to advantage in swamps, where the haul is short, and is largely used throughout the South.

Mr. Spencer Miller described this system in a paper before the Society, which was recently published. That gentleman made a number of improvements upon this system.

Mr. Dickinson, of the Trenton Iron Company, has invented and patented an ingenious system of cableway for logging in swamps, and the plant is an improvement over the Butters system in that it is designed to go further into the swamps. It is put up like trolley wires, the trees being used for the upright supports, which in the trolley system are on either side of the street. A movable block is placed upon the supporting cables, and upon these blocks the main cable is hung. This has not been put into practical use however.

The difficulty with this system is the necessity of finding the trees in just the positions needed, and the fact that the hauling cable has no support, but drags upon the ground.

What is known among lumber-men as a "pull boat" is quite generally used in the cypress swamps of the South. It is designed on the principle of "main strength and awkwardness." A steel cable is carried into the swamps and passed around a large sheave, and a ½-in. cable is attached to the end of a larger cable. A large double drum engine is used. By winding in the ½-in. cable, the larger cable is pulled out into the swamp, and by attaching the logs to the larger cable and winding it on the drum the logs are hauled in.

This system is limited to the length of rope that can be conveniently wound on the drum.

The problem that confronted the writer was to design a cableway that could be operated at least ½ mile, with the power placed upon a boat or car located at a navigable point. It should gather in the logs for at least 500 ft. on either side of the cableway proper, and by its means bring the logs to navigation at a reasonable cost for operation. It was necessary that such a system should be easily and cheaply moved from place to place as the total area of forest to be cleared at any one setting would not require much time. Trees had to be used as supports as they are the only practicable foundation to be found in a swamp. It was evident that any steam system would have to be worked in practically a straight line.

To attempt to find trees in a straight line would be difficult if the distance apart was not great, but after running a number of lines, it was found that in a forest of ordinary density a practically straight line could be gotten with trees at from 100 to 225 ft. apart.

The writer's system was designed for long spans in consequence.

The accompanying drawing (page 47) shows the T iron brackets that were used for passing by the trees, and for supporting the cable. The end of the T iron bar straddles an 1½ × ½-in. iron pin driven into the tree at a height of about 13 ft. from the ground. The dogs on the ends of the arms attached to the T iron bar are driven into the tree on either side, and a chain wrapped around the arms and held from slipping by upset knobs keeps the arms from spreading. This chain also serves to hold an iron snatch-block.

A swinging sheave is hung from the end of the T iron bar on which is an iron band curved rearwardly and downwardly, which acts as a fender and also replaces the hauling cable, should it become disengaged from the hanging sheave. The steel saddle at the end of the

PLATE VI.
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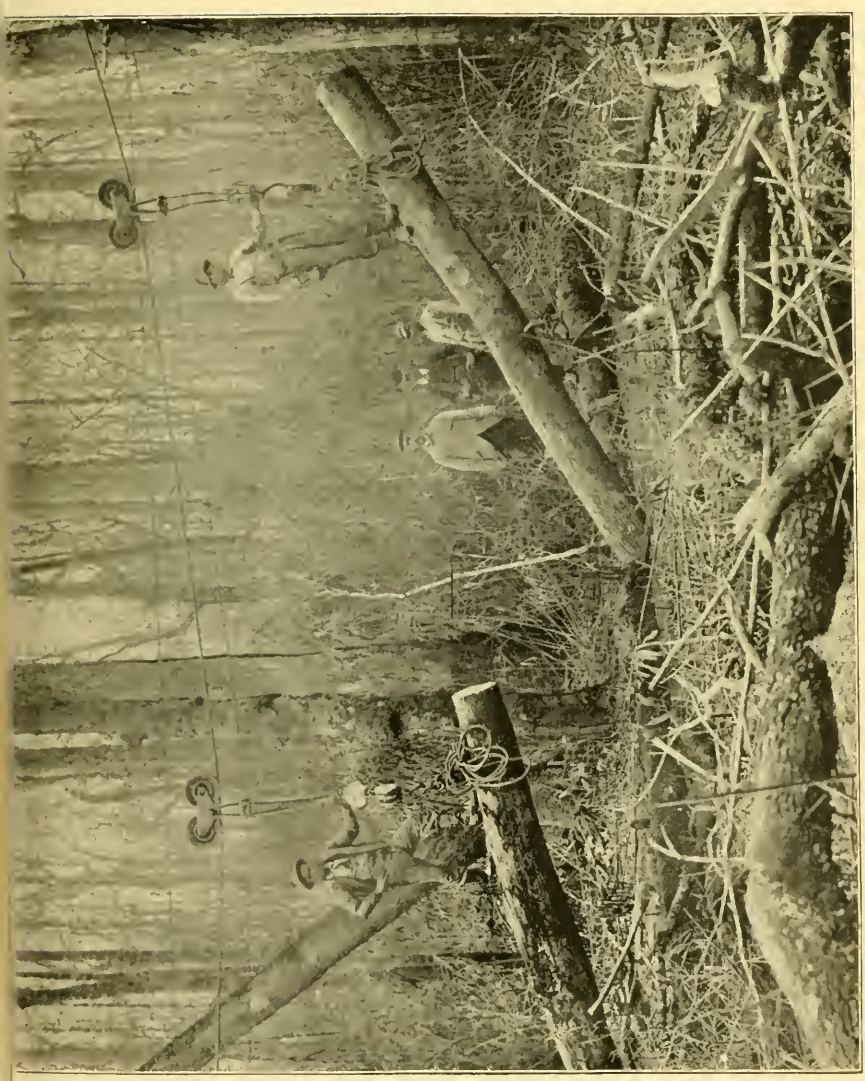
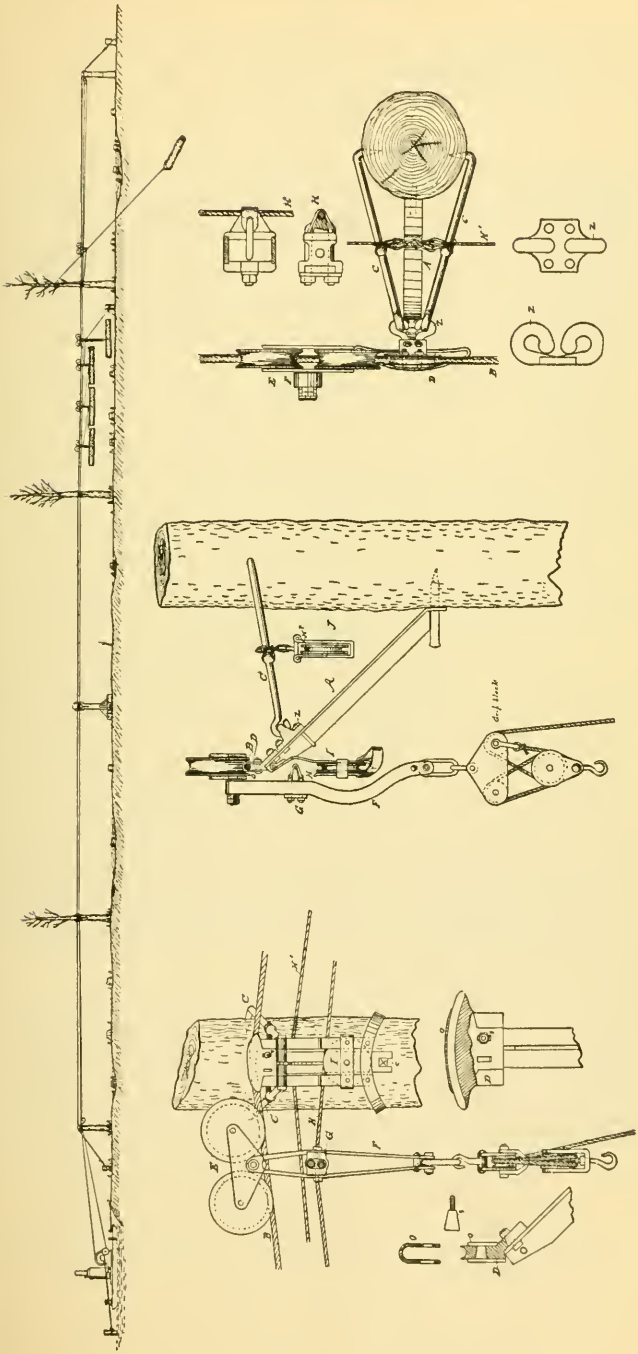
LAMB ON STEAM AND ELECTRIC CABLEWAYS.





T bar is provided with boiler steel U plate. Two wedges pass through the U plate and saddle in opposite directions to each other. By means of these wedges the U plate clamps the main cable rigidly to the saddle.

On the head tree two sheaves are placed, one on either side, and on the tail tree a 2-ft. steel sheave is chained.

The endless ½-in. pulling cable, made of 19 strands of steel wire, is passed through the sheaves on the head tree and on the brackets and around the large sheaves on the tail tree. Two turns are made around a 2-ft. elliptical grooved sheave, run by a 25-H. P. engine for ½-mile line. The engine is made reversible.

After the ½-in. cable is out, the main cable is hauled into the swamp by steam-power by means of the hauling cable.

The main cable is 1 in. in diameter and is of patent interlocked steel, which gives a better wearing surface. This cable cannot be made in longer lengths than 450 ft., but these are easily joined together by a patent coupling, over which the car passes readily.

The 450-ft. sections are hauled out before coupling them together. Any distance of cable can therefore be very easily pulled out into the swamp.

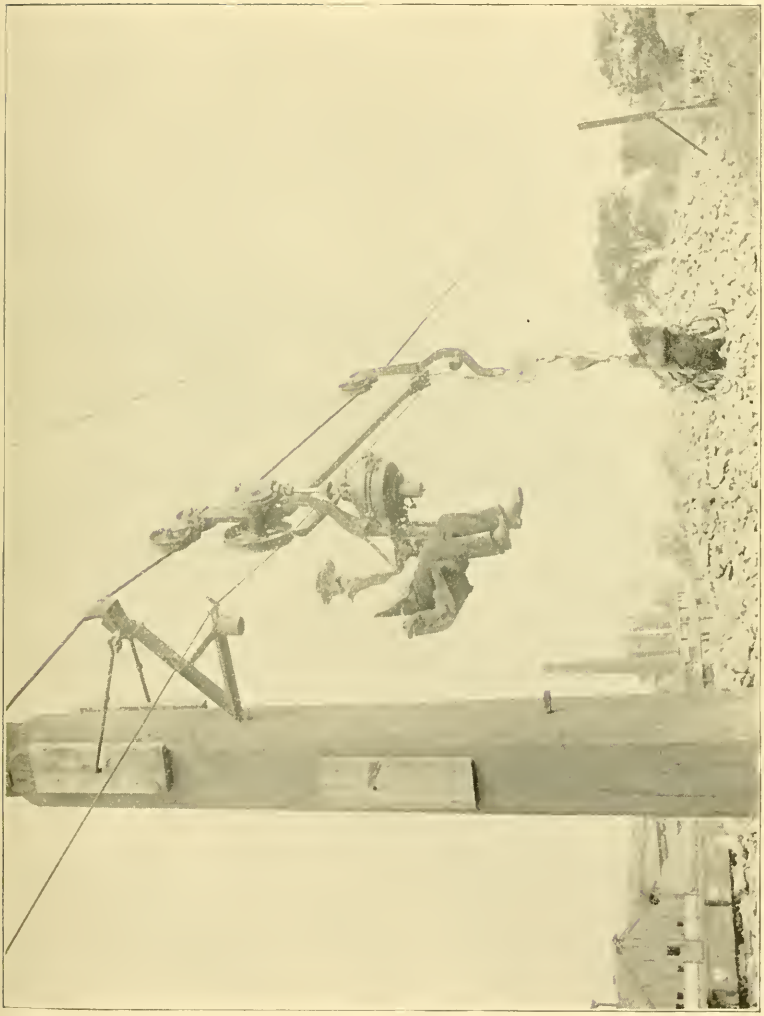
A false saddle is used in putting the cable on the brackets, and has vertical flanges, to keep the cable in place; and rollers are on either end, to reduce friction when hauling the cable taut. After the cable is clamped to the saddle, the false saddle is removed.

The cars are made with a hanging frame supported by a horizontal axle passing between the wheels upon which it swings. By this arrangement the hanging frame can remain vertical even when the car is climbing the steep grade of the catenary on approaching the saddle and when passing over it.

The hauling cable is attached rigidly to the frame of the car at a point located so as to clear the swinging sheave. It will be noticed that the hauling cable is practically parallel with the bearing cable at all parts on the line.

A Detroit grip block is attached to the end of the swinging frame, to which is hung a pair of logging tongs. By securing the bight of the rope of the grip block about a tree or stump and pulling in on the car by means of the hauling cable, the two blocks are made to meet and thus haul up the log. The grip keeps the blocks from parting

PLATE VII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 716.
LAMB ON STEAM AND ELECTRIC CABLEWAYS.



until it is desired to drop the log, when by pulling a string on the grip the log drops. This does away with the difficulty heretofore experienced of the necessity for a separate cable and a separate drum on the engine to haul the log up to the car.

In order to haul the logs from either side up to the cable, trees are chosen within about 15 ft. from the cable, or the tail or bracket trees are used, up to which to pull the logs. A 10-in. sheave is chained as high up the selected tree as may insure sufficient stiffness. Another 10-in. sheave is chained to the tree a little below the level of the cable and a third 10-in. sheave is fastened in a horizontal position to the cable at the end of the bracket, or at the end of a temporary strut placed between the tree and the cable.

A ½-in. cable is attached to the car and the loose end passed through the horizontal sheave; thence through the lower sheave on the tree; thence up the tree, and through the upper sheave.

A pair of double tongs made to operate in lines at right angles to each other are attached to the end of the cable and carried into the woods. The tongs are clamped to the end of a log and act as a fender or guide, to prevent it from bringing up against stumps or other obstructions when being hauled into the cable. By hauling in the car, which is attached to the end of the skidding rope, heavy logs are easily dragged to the cable. When the road under the cable is very rough, the logs to be hauled by the main cable are swung from their centers and joined together with dogs and chain, to keep them in line; but in general it is found that simply attaching tongs to the ends of the logs and raising them from the ground and letting the other ends drag answers all purposes.

Not counting the tree cutters, an engineer and fireman (who also cuts wood for fuel when not firing) two tongmen, one loader and one unloader, in all, six men, constitute the crew. On dry land 40 000 ft. per day can be hauled; in the swamps, 25 000 ft. per day can be gotten out. The saving in cost of hauling over any other method of logging is obvious, but this system also saves money in that it gets out timber that heretofore has not been accessible.

For persons operating a logging railroad or on a river where from ½ to 1 mile of cableway is sufficient, the above-described steam logging system is sufficient.

It became necessary, however, to design a system that practically

would not be limited as to the distance it could be operated. To this end an electric cableway was built. Investigations showed that other systems of telpherage had been tried, but few had been put into practical use, owing largely to the expense of having to make the supports close together, so that the cable might be perfectly taut, as the limited friction area of the wheels on the cable, and the inclination of the catenary near the supports, made it impossible for the car to climb the incline. The power being applied to the wheels, and depending upon traction, they would slip down the grade while they were revolving to make them climb up. Again, there could be no brake to keep the car from slipping too fast after passing over the saddle. As economy and ease in moving depended upon being able to use a few supports, or, in other words, long spans in the forest, it was evident that no system of traction was available. The direction of the force should be parallel to the bearing cable. This suggested the use of a ½-in. cable, made fast at both ends, to be supported at the tree brackets by a narrow saddle, so designed as to enable the cable to change its course and not to become disengaged when the car passed over it.

The motor is made with the car like the steam cableway before described, with a hanging frame having attached to it an elliptically grooved sheave which is revolved by means of a newly patented worm or wedge-gearing, driven by a 5-kilowatts electric motor with vertical shaft, all attached to the swinging frame of the car. By taking a couple of turns of the ½-in. cable around the elliptical grooved sheave, when the electric motor revolves the gearing, the sheave winds up, and at the same time plays out on the ½-in. cable, thus pulling along the car.

When it reaches the bracket, the small cable is lifted from the saddle momentarily, and the car can take a new course. Hence we are not limited to operating in a straight line. The main cable is used as the electrical conductor. It is insulated at the brackets by insulating material placed between the saddle and the T iron bar, and the current is prevented from passing down the frame of the motor by insulation at the point on the frame where the axle-box joins the frame proper. The points of insulation are provided in their construction with hoods to shed water.

The worm or wedge gear deserves especial mention. It was invented in 1891 by a Mr. Welsh, of the Glen Cove Machine Company.

PLATE VIII.
TRANS. AM. SOC. CIV. ENGRS.
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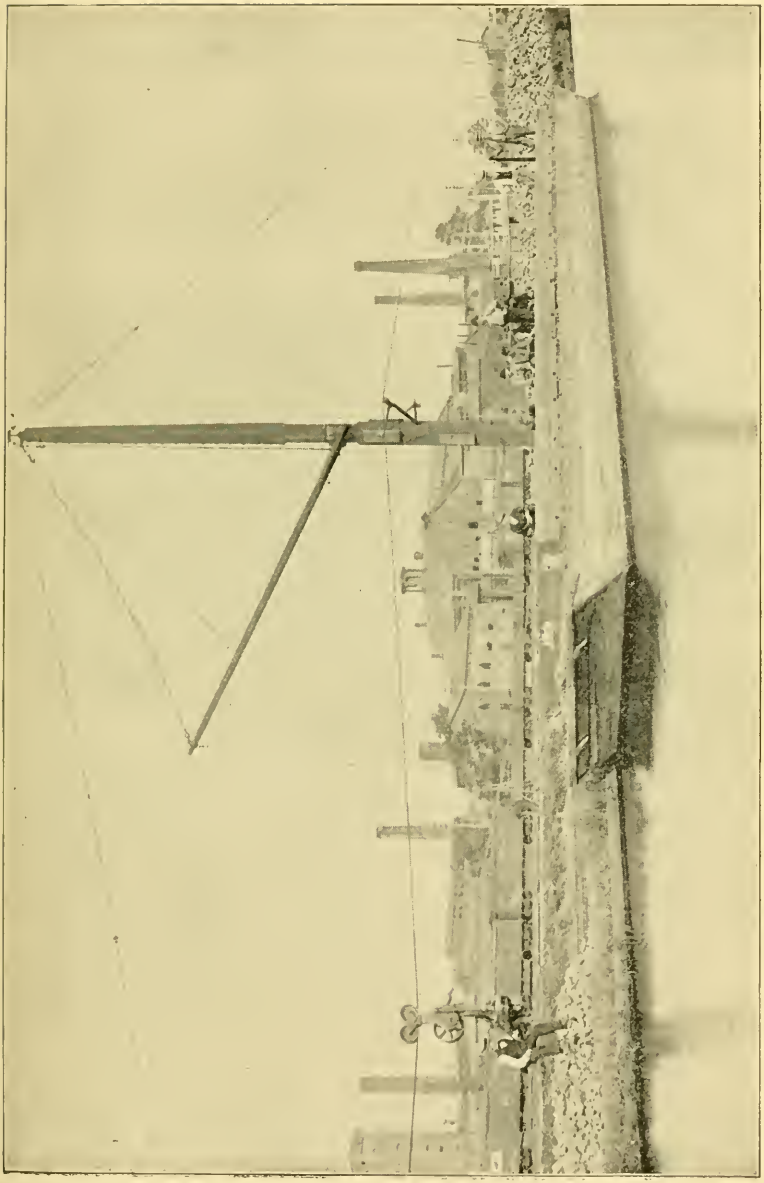
LAMB ON STEAM AND ELECTRIC CABLEWAYS.



It differs from an ordinary worm gear in that it has more than twenty times the bearing surface of an ordinary worm and wheel, moves two teeth of the gear wheel at each revolution of the worm, and works on the principle of a wedge rather than an incline plane. The worm gear, especially made for this electric motor, is designed to work both ways, and has ball-bearings at either end of the worm, to lessen the friction and thrust. The gear wheel, worm and ball-bearings are encased in a jacket filled with oil. Thus the minimum loss in power is effected between the electric motor and the elliptical grooved wheel. The gearing was necessary in order to lessen the speed, as the electric motor is run at 1 340 revolutions per minute, giving a speed to the motor proper, with the gearing, of 6 miles per hour, which is the desirable speed for logging purposes. The current is taken from the main cable through the wheels, thence through the axle to the axle-box of the hanging frame. Here an insulated copper wire connects it with the rheostat. The return current is passed through the axle of the elliptical grooved wheel; thence on to the ½-in. wire to the brackets; thence to the ground.

The rheostat is made to carry the current through it, as well as to regulate the speed and reverse the current.

In the system now built 220 volts are used. The trial was made at the works of the Trenton Iron Company, Trenton, N. J., along the banks of the Delaware and Raratan Canal. It was found that heavy logs could be pulled from a distance up to the cable by the same method as employed in the steam system, and that logs could be carried in the same manner as stated in the description of the steam rig.

When two motors are used, the empty cars are switched off the cable, and motors are exchanged, the motor which hauled the empties taking back the loaded ones, and *vice versa.* This system of electrical cable-way can be used for an endless variety of purposes.

A valuable service for this new motive power was tested, viz., towing canal boats. It will be obvious that a cable can be located on a towpath, and at either end of the canal can be built sheds in which there would be a large number of motors ready to go out. On application of a canal boat captain, a motor will be allotted to him, and he will proceed, towed with a tow-line having insulated wires in the center of same. The rheostat will be located on the canal-boat.

The wires in the hawser can be easily attached to or detached from the rheostat. When a boat meets another, they change hawsers and consequently motors, and proceed. Two lines of bearing cable would do away with this trouble.

The cheapness with which this system can be built and operated would insure the saving of thousands of dollars in the operation of such a canal as the Erie, especially as that canal has at its disposal the almost limitless electrical resources of the great Niagara cataract.

DISCUSSION.

Spencer Miller, Assoc. Am. Soc. C. E. (by letter).—The "pull-boat" system referred to by Mr. Lamb is known as the Baptist plan. The hauling power is an engine made after the manner of the cable railway engine, and is located on a boat, which may be floated in the bayous or canals. The hauling cable reaches into the woods 3 000 ft., passing round a sheave wheel as the far end, known as the tail tree.

An important element of the Baptist system for handling logs is the use of a hollow cone, made of steel, whose base is about equal to the diameter of the log being hauled. Through the apex of this cone a chain is passed with tongs or dogs on the end, which are secured to the log. This chain is made fast to a clamp on the endless rope, and they are thereby drawn in over the surface of the ground at a rate of speed of about 500 ft. per minute. Whole trees are pulled in this way.

The chief value of such a device lies in the fact that there are the smallest number of parts to get out of order and need attention. The cone serves to clear the log over any obstacles, such as stumps, etc. It requires, of course, a large amount of power, which means a large engine has to be purchased, but inasmuch as the waste wood is burned, the cost of fuel is a trifling matter.

The Baptist plan suits some conditions better than the Butters, and it is reasonable to suppose that Mr. Lamb's system, which extends still further, will have its place.

My observation leads me to expect that a great many locations will be better served with that machine than with anything else. However, I would like to hear from Mr. Lamb a year from now, after he has had the machine in use for that length of time, under the conditions which he will find in the woods. I have not had the pleasure of seeing this machine as yet.

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719.

(Vol. XXXII.—July, 1894.)

BRAFFORD'S RIDGE TUNNEL.

By CHARLES W. STANIFORD, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

This tunnel is located nine miles from Corbin, Ky., on the Cumberland Valley Branch, Louisville and Nashville Railroad, the first 32-mile division of which, from Corbin to Pineville, Ky., was built in 1887-88, under the supervision of the writer as Division Engineer, assisted by Mr. M. E. S. Posey, Resident Engineer of the 2d Residency (including tunnel), and under the general direction of R. L. Cobb, M. Am. Soc. C. E., as Chief Engineer of Construction, Louisville and Nashville System.

The line for the whole length of the division follows very closely what is known as the old "Wilderness Road," celebrated as the trail taken by Daniel Boone on his first entry into Kentucky, at Cumberland Gap nearby, and also as the marching and camp ground of both armies during the Civil War. In many places this road had to be changed and relaid higher on the hills, away from the Cumberland River, in order to give a footing for the railroad, where it is hewn out of the river cliffs.

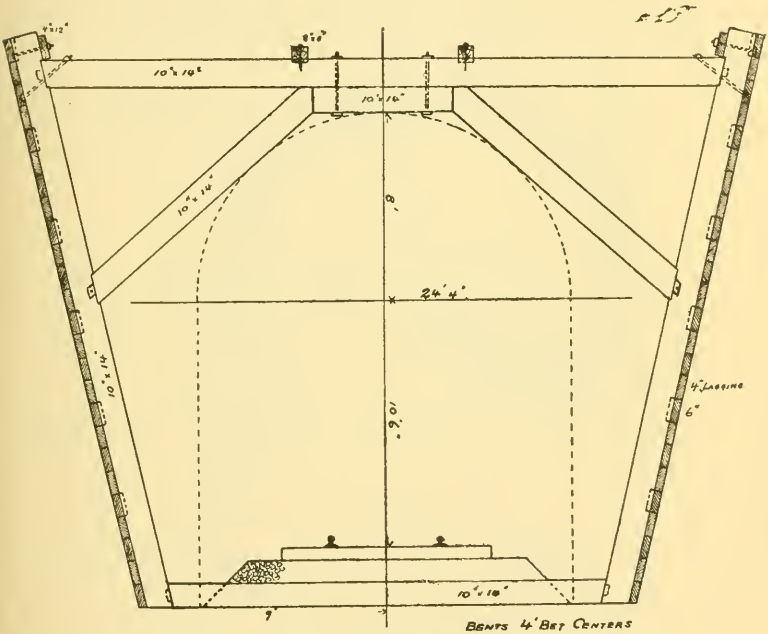
The Gap at Brafford's Ridge, both from a geologic and topographic

standpoint, was unfavorable for the construction of a tunnel. The rock encountered at the portals was a brittle, heavily laminated shale, which, although easy to work, disintegrated rapidly on exposure, rendering support, temporary or permanent, necessary. The overlying material, which would have to be penetrated by either an open cut or the approach cut to a tunnel, was a wet gravel with many boulders, very treacherous to work, and hard to maintain. Steep rising slopes adjacent to the line in this material (see Plate IX), made it undesirable to go down so low as the approach cut to a tunnel would necessitate.

It seemed that the thing to do would be to raise the grade high enough, not only to avoid a tunnel, but to get a reasonably light cut, even at a great increase in the maximum grade. The formation of the surface on each side of the ridge in this vicinity made it impracticable to do this, as the western approach was an elevated, but very flat country, giving no supporting ground on which to develop a grade line; while on the eastern side of the hill the ground dropped off very rapidly, so that on our maximum grade of 66 ft. per mile we reached the bottom lands near the Cumberland River, in about three miles from the summit.

A tunnel being necessary, it was decided to line it with timber at first, and to replace the lining in time with more permanent support if necessary. In the east approach cut, after working into this soft material with its steep slope, it was found that a self-supporting cut was impossible, and timbering was commenced about 300 ft. from the portal, with a section as shown in Fig. 1. The upper portion of the cut was taken off first, in order to give an entry into the heading (Plate IX), sloped only enough to stand temporarily. At the same time a force started at grade, sloping 1 to 1 as far as possible. The side batter posts were then placed as soon as sufficient material had been removed to get them into position, after which the straining beam, braces, lagging, etc., were framed in place, and the rear filled in and packed evenly on each side. The timbering was started by spacing the bents 6 ft. between centers, but after an exceptionally heavy rain, lasting several days, the side batter posts commenced to bend under the pressure. Only six bents had been put in at this time, so the distance between centers was reduced to 4 ft., after which no section of the timbering showed any signs of weakness, and the six bents mentioned were re-enforced by an extra bent between each.

It was intended to work most, if not all, of the tunnel from the east portal, so as to avoid the water which would back up in the down grade on the west side, and also to take advantage of this favorable grade for the transport of material. It became evident, however, that if so prosecuted, the work would not be finished with the balance of the road, owing to trouble experienced with water in the west approach, and with the timbering on the east side.



Section in Approach Cut

Fig. 1.

The west approach was worked by taking off the surface of the cut and running an incline to strike the heading as soon as possible. After the headings had met, much of this cut remained to be taken out, so that, in order to commence on the bench at each end, another drift was inclined to meet grade of the tunnel near the portal. This material from the bench was hauled out on a narrow berm, along the crest of the cut.

When the work was near completion, but before the benches had met, it was seen that although the tunnel would be finished on time,

the approaching track-laying would be delayed by the west cut not being out; another bench was started at grade in this cut near the portal and worked westward. This method of procedure formed a vertical face, and left no runway for the disposal of material, so a derrick was placed above the face on top of the cut, the rock hoisted in car bodies, then placed on other trucks, and hauled along the berm to the waste dump (see Plate IX).

The points selected for portals made the length of tunnel 843 ft., and the section adopted (see Fig. 2) was the five-segment roof,

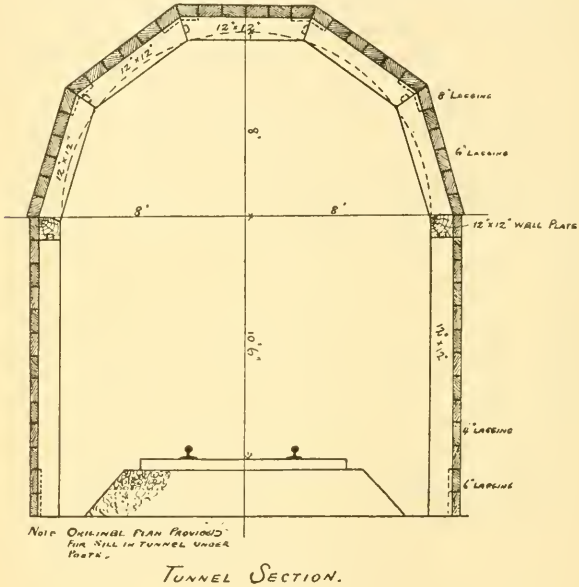
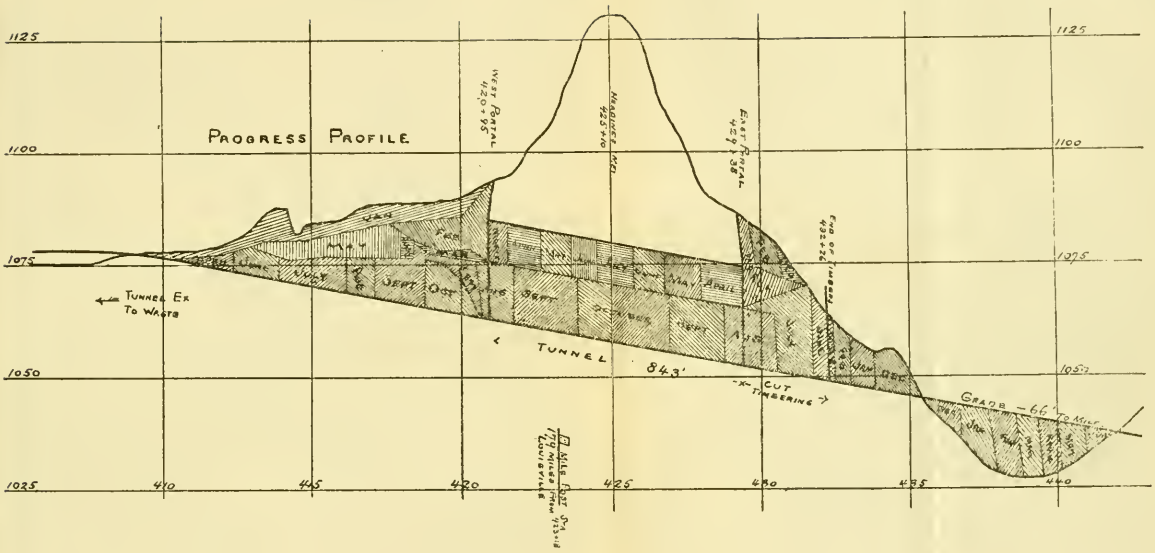
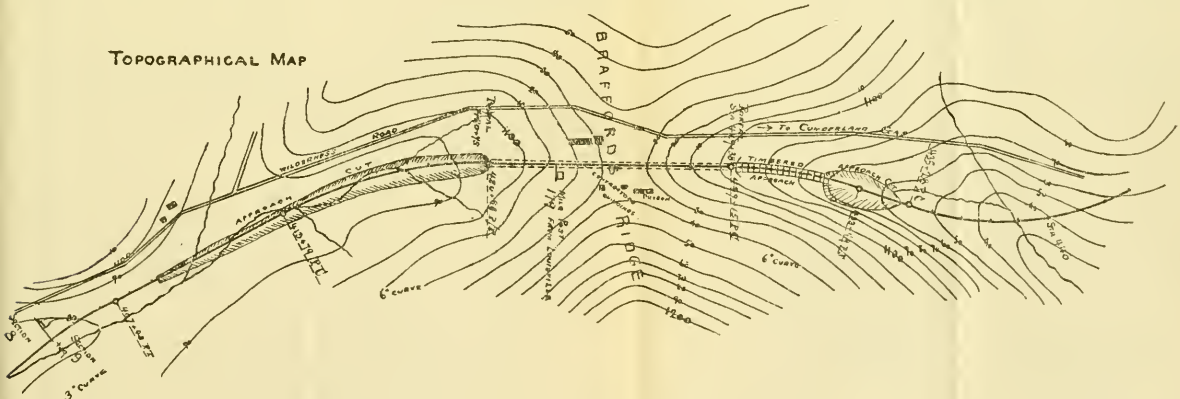


Fig. 2.

coinciding with an 8-ft. radius circular arch at the joints, with bents 4 ft. between centers. Roof ribs, side posts and wall plates of 12 x 12-in. timber, mortised and tenoned at upper joints in roof, and at upper end of posts into wall plate. Lagging, 6 ins. thick in roof, except at joints where 8-in. was used, with 2-in. dap; on sides, the lagging was 4 ins. thick except two lower courses where 6-in. timber was used with 2-in. dap.

All drilling was done by hand, the holes being placed so as to blast out the interior section without disturbing the outside limits or


PROGRESS PROFILE
1125
1100
1075
1050
1025
410
415
420
425
430
435
440
TUNNEL EX TO WASTE
TUNNEL 843'
CUT TIMBERING
GRADE - 66'
WEST POINT 1120.95
HIGHEST POINT 1125.10
EAST POINT 1129.68
END OF TUNNEL 432+26
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
APRIL
MAY
JUNE
JULY
AUG
1/4 MILE EAST OF 1/4 SECTION LINE


TOPOGRAPHICAL MAP
BRAFFORD'S RIDGE
TO CUMBERLAND
WILDERNESS ROAD
CUT
APPROACH
TIMBERED
6° CURVE
3° CURVE
1400
1300
1200

the roof. Small holes and charges were then carefully placed and fired to try to approximate the shape of roof required. This was usually accomplished, and at the same time taking out very little material outside the normal section. A blast so shattered the rock, however, that in order not to bring down any more than was absolutely necessary, the timbers and lagging had to be placed as soon as enough space had been mined for them, after which the void space in the rear was carefully packed with rock laid dry.

MONTHLY PROGRESS IN HEADING.

Month ending—	West End.		East End.		Both ends. Total.	Both ends. Monthly.	Feet remaining.
	Total.	Monthly.	Total.	Monthly.			
March 31st.....	65	65	...	...	65	65	778
April 30th.....	180	115	138	138	318	253	528
May 31st.....	285	105	258	120	543	225	300
June 30th.....	355	70	358	100	713	170	130
July.....	415	60	428	70	843	130	...

The headings were commenced March 15th, and finished July 15th, 1887. The size approximated a semi-circle of 9½ ft. radius, giving about 5¼ cu. yds. per linear foot.

The maximum progress in heading for one month in east end was 138 ft.; average monthly progress about 122 ft., or 641 cu. yds.

The maximum progress in heading for one month in west end was 115 ft.; average monthly progress about 104 ft., or 546 cu. yds.

WEEKLY PROGRESS ON BENCH.

Week ending—	West End.		East End.		Both ends. Total.	Both ends. Weekly.	Feet remaining.
	Total.	Weekly.	Total.	Weekly.			
August 13th.....	15	{3 days 15}	...	...	15	15	828
August 20th	40	25	21	{3 days 21}	61	46	782
August 27th	75	35	45	24	120	59	723
September 3d.....	92	17	92	47	184	64	659
September 10th....	136	44	152	60	288	104	559
September 17th....	184	48	190	38	374	86	469
September 24th....	232	48	235	45	467	93	376
October 1st	274	42	274	39	548	81	295
October 8th.....	328	54	321	47	649	101	194
October 15th.....	391	63	380	59	771	122	72
October 19th.....	423	{3 days 32}	420	40	843	72	...

The bench was started August 10th, and finished October 19th, 1887; size about 13 ft. x 19.66 ft., or 9.58 cu. yds. per linear foot.

The maximum weekly progress on bench at the east end was 60 ft.; maximum at west end, 63 ft. The average weekly progress for total of both ends was about 84 ft., or 805 cu. yds.

The headings met with about 0.02 variation in alignment, and practically no difference in grade. The roof timbers all came to true even bearings, showed no settlement or warping, except in one place near the portal at the east end, where, in starting the bench, too long a section was left unsupported before putting in the plumb posts under the wall plate, causing a slight settlement and outward movement of roof towards portal. This was remedied by placing longitudinal bracing outside the tunnel, which was afterwards taken away when the timbering in the cut came flush with the tunnel portal. All posts, lagging, etc., were after this put in as soon as enough rock had been removed for them, avoiding any further trouble from settlement.

White oak was the only available hard wood and was used for the lining in tunnel and approach. It was sawed and cut at temporary mills in the mountains, distant about one mile, then hauled to the work and framed to sizes outside the tunnel.

All labor at the tunnel and approaches (except the actual work in framing timbers together, after they had been placed in position) was performed by Kentucky State convicts, the contractors having the lease of the penitentiary at Frankfort, and employing a certain number on railroad work, where they could be used to advantage in different parts of the State. The unsettled condition of the people in this mountainous country, and their aversion to the advent of the road, rendered it difficult to persuade the average colored laborer to remain long in one place, so that the question of labor, and how to keep it, was of the utmost importance to a contractor, who looked towards finishing his work in time to satisfy the company. For this reason the regular convict system, with the men always under perfect control, for day or night duty, rendered them almost invaluable for work at a tunnel in a country like this, where its delay meant the holding back of a whole line of road. They were worked in gangs of from 10 to 15 men under a foreman and guard, one guard at each portal protecting the tunnel, and were used elsewhere on this division only for work at bridge foundations, and in track-laying.

The writer will state in passing, that contrary to many newspaper and magazine articles he had read, criticising the system throughout the South, curiosity led him to inquire into the matter, and from personal observation at this tunnel he found the men (mostly colored) well treated, with comfortable quarters, plenty of plain but good food, and as a rule better contented than he had often seen convicts within prison walls. There were only two or three attempts at escape during the construction of the tunnel, and not any while track-laying was in progress, where the chance for successful escape was much greater.

The total cost of the work was as follows:

Tunnel.		
Excavation, 12 513 cu. yds. at $3 50.....	$43 795 50	
Packing, 1 309 cu. yds. at $2 00.....	2 618 00	
Timber, 415 344 ft., B.M., at $24 50.....	10 175 93	
		$56 589 43
Approach Cut—West Side.		
Earth excavation, 3 567 cu. yds. at 13½ cts..	$481 55	
Loose rock excavation, 8 331 cu. yds. at 50 cts.	2 915 85	
Solid " " 1 826 " " 70 cts.	1 278 20	
		4 675 60
East Side.		
Earth excavation, 7 216 cu. yds. at 13½ cts..	$974 16	
Loose rock excavation, 1 509. cu yds. at 35 cts.	528 15	
Solid " " 2 526 " " 70 cts.	1 768 20	
Timber, 302 569 ft., B. M., at $24 50.....	7 412 94	
		10 683 45
Total.....		$71 948 48

Mason, Hoge & Company, of Frankfort, Ky., were the contractors for the whole 32 miles, the first 10 miles, including tunnel, being sublet to Messrs. Mason & Dickey.

DISCUSSION.

Joseph Strachan, Assoc. M. Am. Soc. C. E. (by letter).—Some notes as to cost of work and method of tunnel driving pursued on the South Pennsylvania Railroad, gathered during the progress of that work,

from 1883 to 1885, may be of interest in connection with Mr. Staniford's paper on the "Brafford's Ridge Tunnel."

The residency with which the writer was connected contained the Kittatinny and Blue Mountain tunnels, known as the "Twin tunnels," on account of their close proximity to each other, there being only 750 ft. between their adjoining portals.

All four approach cuts were through shale rock of the Hudson River and Clinton formations, with 1 500 ft. of Medina sandstone near the middle portion of each tunnel.

No shafts were used in driving either of these tunnels.

The lengths from portal to portal were: Blue Mountain, 4 240 ft., and Kittatinny Mountain, 4 620 ft.

About 3 280 ft. in length of these tunnels was driven for double-track road with an extreme width inside of masonry, at the springing line, of 27 ft., and a height from rail base to soffit of 20 ft. 6 ins. The section was excavated 2 ft. below rail base for drainage and ballasting of track. Where masonry lining was used, the side walls were of second-class masonry, laid in cement mortar. These side walls were 2 ft. thick at springing line of arch, with a straight back and a face battering 6 ins. in a height of 10 ft. 3 ins.

A three-center brick arch, 2 ft. thick, was sprung from these walls, with radii of 10 ft. 9 ins. on the under side of arch, from the springing line at each side through 45° of arc, and a radius of 14 ft. 8 ins. through 90° of arc joined the upper ends of the arcs of smaller radius and completed the arch. Dry stone packing filled the space between the back of the masonry and the rock.

The west end of Blue Mountain Tunnel was the only place where pumping was necessary, the grades at the other points being sufficient to properly drain the tunnels.

At both ends of Kittatinny Tunnel and at the west end of Blue Mountain Tunnel the method of driving was with a heading carried 75 to 100 ft. in advance of the bench, which latter was at once taken out to grade.

At the east end of Blue Mountain Tunnel, while excavating for double-track road, the bench was run up grade for several hundred feet, the heading about 100 ft. in advance of this upper bench, and a third force followed, taking out the material to grade on one side of the tunnel, leaving a berm on the other side wide enough to allow the cars from the upper bench to carry the muck from the heading and the upper level, to the dump.

One or two men were detailed to follow the bench force and trim the roof, for a peculiarity of this shale was that what appeared to be a very solid roof would, after exposure to the air for a few days, disintegrate, and large chunks would occasionally fall, sometimes with serious results to the laborers in the tunnel.

A compressor plant for driving the drills was located at each end of Blue Mountain Tunnel.

For Kittatinny Tunnel a compressor plant was located in the valley between the hills, and a 3-in. iron pipe was run over to the westerly heading; the single compressor thus operating both ends of this tunnel.

The reduction from double-track to single-track section was made by sliding the half section for double track sideways for 11 ft. on to the other half section, thus reducing the width of the section to 16 ft., and its height to a little over 21 ft., the resulting section showing a pointed arch.

No masonry for single-track tunnel was built, but at the west end of Blue Mountain Tunnel timbering was used for both double and single-track sections.

Single-track rock section required an excavation of 10.7 cu. yds. per foot run. The heading in single-track tunnel was usually about 12 ft. wide, and from 6 to 7 ft. high.

The holes drilled for the "cut," as the first holes in the face of the heading are termed, were usually eight in number, four on each side of, and about 4 ft. from, the center line, and, vertically, about 2 ft. apart, 7 to 8 ft. deep, and the upper hole on each line from 3 to 4 ft. below soffit grade.

"Squaring-up" holes were arranged in a manner similar to those of the "cut," and the lines about 6 ft. each side of center line of tunnel.

An additional hole at the top of the heading on center line was drilled for a top enlargement, and two holes at about the level of the springing line of the arch, and within 1 or 2 ft. of the lines of tunnel section, were drilled for side enlargement.

The heading force drilled the "cut" and "squaring-up" holes, and a second force the top and side enlargement holes, while a third force of drillers took care of the bench.

The holes drilled for the "cut" were inclined toward each other about 30°, so that a wedge-shaped section of rock was blown out, and as little force as possible wasted one side of the center line in neutralizing the force from the other side. The holes for the "square-up" were inclined slightly away from the center line, to get all the "cut" missed. Four holes across the 16-ft. width of tunnel were drilled to blow down the material to the bottom of the tunnel. When the heading floor was carried quite high, the material between it and bottom grade would be worked in two lifts.

From observations taken, the amount of explosive used for the "cut" varied from 75 to 100 lbs., according to depth of holes. The explosive contained from 40 to 60% dynamite.

Through the shale rock about 20 hours were required from the

beginning of one cut to the beginning of the next, *i. e.*, for the drilling, loading and firing of the heading holes and setting up drills to begin again. Through the sandstone from 25 to 27 hours were required for these operations.

The prices paid for tunnel excavation were: Blue Mountain, double-track tunnel, $3 per cubic yard, and $3 45 per cubic yard for single-track tunnel. At the Kittatinny Mountain Tunnel the prices were $3 25 and $3 50 for double and for single-track tunnel respectively. Second-class masonry, $8 per cubic yard; brick masonry, $12 per cubic yard; dry packing, $3 per cubic yard.

Force account was taken each day over the entire work and an estimate of the cost of the work to the contractor was calculated and sent to the Division Engineer with the monthly estimate of work done.

From observations made during the spring and early summer of 1885, the total cost to the contractors for East Blue Mountain heading, in Medina red sandstone, dipping 75° west, with a section requiring an excavation of 10.7 cu. yds. per foot run, was $7 39, and for bench was $4 10 per cubic yard; average haul by cars, 2 800 ft.

At West Blue Mountain heading, through olive shale of the Clinton formation, dipping 70° west, the cost was $4 16, and for bench $1 63, with a tunnel section of 15.6 cu. yds. per foot run, and an average haul by cars of 1 700 ft.

At West Blue Mountain, through olive and red shales with 5% sandrock, dipping 70° west, and a tunnel section of 11 cu. yds. per foot run, heading cost $4 50, and bench $2 67 per cubic yard; average haul by cars, 2 200 ft.

At East Kittatinny, through olive shale with 5% sandrock, dipping from 6° to 30° east, and a very wet heading, with a tunnel section of 10.7 cu. yds. per foot run, the heading cost $4 69, and bench $2 42 per cubic yard; average haul by cars, 2 350 ft.

At West Kittatinny, through red Medina sandstone, dipping 84° east, with a tunnel section of 10.7 cu. yds. per foot run, heading cost $8 38, and bench $3 43 per cubic yard ; average haul by cars 2 400 ft.

The above figures were obtained by observing, as closely as possible, the force account at the different points and estimating the interest on cost of plant and depreciation of same, cost of small tools, fuel, transportation and explosives used.

Weekly progress reports were issued from the office of the Associate Engineer at Harrisburg, and a file of these, running from July 4th, 1885, to October 10th, 1885, shows a maximum weekly progress in heading of 65 ft. at East Kittatinny, and on bench of 52 ft. at the same place. The average heading progress for seven weeks, just previous to the orders to close down, was about 21 ft., and on bench was 24 ft.

During the progress of the work, notes were taken along the side walls of the tunnels of the dip of the rock strata, their thickness and

location by stations, and this information was plotted on a large scale for record.

When the alignment of the tunnels had been carefully made, the length between portals was measured by lining in large stakes with a nail driven into the top of each and near enough together to measure with a 100-ft. steel tape the distance between the nails on the slope of the hill. Careful levels were then taken on the nails, and the horizontal distances between them calculated in the office and summed up for the lengths of tunnels.

It was not our good fortune, however, to be able to "check up" line and levels through these tunnels.

The work was abandoned November, 1885, the headings of the Blue Mountain Tunnel being then 1 180 ft. apart, and those of the Kittatinny Mountain Tunnel but 570 ft. apart.

I believe no further work has since been done on the South Pennsylvania Railroad.

Mr. William F. Shunk, of Harrisburg, was Associate Engineer, with Mr. Robert H. Sayre as Chief Engineer of this road, and William H. Atwood, M. Am. Soc. C. E. (now deceased), was Division Engineer over about 32 miles of very heavy work which included these tunnels.

W. M. Hall, M. Am. Soc. C. E. (by letter).—Having done much similar work to that described by Mr. Staniford, I have read his paper with interest. To me the points of most importance are, first, the progress made with hand drills; second, the method of timbering approach cut; and third, his comments on convict labor.

As hand drills were used throughout, of course, his progress was limited by the drilling. For that method I note his tunnel progress was very fair; and in this connection I wish to say that for short tunnels of less than 2 000 ft. length, where time is not a matter of the very greatest importance, that even in this age of machinery it is the best manner of doing the drilling. In saying this, I mean it is best for both the contractor, who wishes to take out the excavation at the least possible cost, and for the owner of the tunnel, who wants it completed in the most substantial manner at the least possible cost.

In these days of cheap explosives and machine drills the inclination is to put in holes from 6 to 9 ft. in depth. These deep holes often injure almost or entirely beyond repair what could with shorter holes be made a good substantial rock roof. They also make the breakage outside of the desired section excessive. With machine drills every tunnel foreman wants to take out just as deep a cut as he can "pull." We can all easily make limits for the depth of these holes, but getting such orders obeyed is a more difficult matter. With hand drills there is no incentive to put the holes deeper than about 5 ft.; and, therefore, the natural roof is shattered very little and a better, and in many cases a good rock roof, is obtained, which, with the use of deeper holes,

would have been ruined, necessitating timber or masonry lining. I believe, therefore, that the engineer who orders or allows plants of drilling machinery put on his short tunnels, except in cases of absolute necessity, is making a mistake.

I read Mr. Staniford's comments on the treatment of convict labor with much interest, and, although this method of employing convicts is so severely criticised by our press, and many of our statesmen, it appears to me far better for any State to make a convict pay for his support and other expense to the State than to further tax the State which he has wronged for the support which he should be made to earn. However, as this is only remotely an engineering question, I will not pursue it further.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

720.

(Vol. XXXII.—July, 1894.)

ON THE MARKING OF STREET LINES.

By C. M. BROOMALL, Jun. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

The writer, being interested in the question by reason of his position as surveyor of a Pennsylvania town, has been collecting data regarding the various methods used in different cities throughout the country "to mark the street lines, what manner of range stones or monuments are used, their location, size, etc.; also what points are used as level benches and to what datum they are referred." The subject at first glance seems a small one to spend much time in investigating, yet when it is considered how much depends upon the unalterability of street lines, there is little doubt but that the experience of all city engineers will lead them to agree upon its importance.

In collecting this data, circular letters were sent to city engineers in all parts of the country. The number of answers received was, of course, in no manner sufficient to show the average practice, but it gave the opportunity of choosing from a large number that which seemed the best practical method, and it was for that purpose the in-

quiry was started. The following is a brief record, with comments, of all the different methods contained in the replies:

First.—The commonest method of marking street lines is undoubtedly by the use of ordinary stone monuments, granite or marble. The usual length of the stones is from 18 to 24 ins., although, as exceptions to the rule, it may be mentioned that the city of Milwaukee, Wis., uses monuments 5 ft. in length; the city of Wilmington, Del., 3 ft. in length; Memphis, Tenn., 3 ft. in length; and Portland, Me., 5 ft. in length. A large number of replies received mention them as being located at the intersections of the center lines of streets, while others have them near the side lines on 3-ft. or 5-ft. ranges. In the city of Erie, Pa., the stones are described as 1 cu. ft. in size, with a copper rivet inserted to mark the line. In Salt Lake City, Utah, the monuments are protected by brick boxes with cast-iron covers. In the city of Jacksonville, Fla., artificial stone monuments are used. The city of Portland, Me., uses monuments of granite 5 ft. long and 8 ins. square, on 3-ft. range lines.

Second.—Iron monuments are used in many cities. In Topeka, Kan., round wrought-iron pins 1 in. in diameter and 30 ins. long were originally used, but now cast-iron pins 1½ ins. in diameter and 30 ins. long are used, the reason given for the change being that the latter cannot be easily pulled out. In other cities iron bolts are used 1 in. in diameter and only 1 ft. in length, driven at the intersections of the center lines of streets. In Memphis, Tenn., iron bolts are used 30 ins. long, with flat heads 2 ins. square, the whole protected by an iron cylinder 20 ins. long and 6 ins. diameter, covered with a heavy cast cover. The same city uses in addition hard limestone monuments 6 ins. square, 36 ins. long, on 4-ft. ranges. The city of Albany, N. Y., has a system of iron monuments with many good points. A detailed description of it given by the City Engineer, Horace Andrews, M. Am. Soc. C. E., states that they use a 5-ft. length of double-hubbed, extra heavy 3-in. soil pipe of tarred cast iron, weighing about 50 lbs. Into one of the hubs a brass cap, about 3 ins. in diameter and 1¼ ins. thick, is leaded, having upon it the inscription, "Albany City Monument." This cap weighs about 2 lbs., and in its center a small hole is drilled, to mark the line.

Third.—Another kind of monument which is interesting and worth description is that used in Salem, Ore. Each monument consists of two dressed stones set vertically one above the other, the lower one

being 5 ins. square and 10 ins. long, and the upper 5 ins. square and 24 ins. long. One quart of charcoal is placed at the junction of the two stones where one stands upon the other. Both stones are marked with a cross and centered. The monuments are set at the intersections of the center lines of streets.

Fourth.—The number of different bench marks used is large. The regular stone or iron monuments of the city, water tables of buildings, stone foundations, hydrants, door sills of buildings, stone copings, curbing, fire plugs, square-headed bolts in the roots of trees, etc.

Fifth.—The different data used are almost as numerous. Of course, the majority of them are purely arbitrary. Sea level is often used, and cities on the lakes use high-water level of the lakes; and others use the water level of such river as they may be situated upon. The datum at Cleveland, O., was established in 1854 as a mark on the Government pier 2 ft. above the then surface of the water in Lake Erie; the City Engineer gives the information that the surface of the lake is now about 2½ ft. lower on the average than at that time. Of course, this change of water level is foreign to the subject of this article, yet reference to it is of interest. Some cities use railroad data taken from the railroads passing through them. The city of Topeka, Kan., uses a datum established arbitrarily and perpetuated by ordinance, which is, unfortunately, so taken that it is above some of the lower portions of the city, and, therefore, in grade calculations it becomes necessary to use plus and minus quantities.

Sixth.—In concluding the description of the different monuments it may be added that it is surprising to find the number of cities that have no system of ranges at all, even such large ones as St. Louis, Mo.; Trenton, N. J.; Charleston, S. C.

Turning now to the choice of the best system of monuments, the writer would like to preface it with mention of the trouble encountered in his own town, where marble monuments from 18 ins. to 2 ft. long are used. As a result of the gradual changing of these stones the alignment and levels check badly, although in the beginning they were supposed to have been set with extreme care. When the frost is leaving the ground in the spring it is no uncommon thing to feel the stones yield under the foot if stepped upon, and the writer thinks there is a possibility at this season, when the stones have risen with the frost, that if a heavy rain should come, the water, by following down their sides,

might wash in the sand or earth under them and hence prevent their return to the original level. Whether there is really any such result following the rising of the stones in the spring he is not prepared to say, although as above mentioned the checking of the levels with what they are assumed to have been originally, is generally unsatisfactory. As far as the lines given by the stones are concerned, it is the writer's experience that in the spring and after heavy rains many of the stones are quite loose, and that a moderate blow will displace them laterally ⅛ or ¼ in., which new position they may thereafter retain.

After careful consideration the writer has formed the opinion that the two systems of monuments hereafter described are the best of their respective kinds, the advantages of one being offset by the smaller cost of the other.

(*a*) Marble stones set on 5-ft. range of either side line of streets, dressed 5 ins. square on top, and dressed down square for the upper 6 ins. of the stone; below this, roughly shaped out, flaring or tapering outwardly to a section 10 ins. square at the bottom, the whole stone to be not less than 3 ft. in length; hole drilled in top to mark the range line and upper surface (to be used as level bench) set just below the sidewalk, so that a loose brick or tile may be used to cover and protect it. A stone of this description, owing to its weight, depth below frost and the wedging effect of the earth upon its inclined sides, would be immovable and in every way fill the requirements of a perfect monument.

(*b*) Iron monuments set on 5-ft. range lines, a modification of the system used in Albany, N. Y., consisting each of a 4-ft. length of extra heavy, double-hubbed, tarred, cast-iron pipe, 4 ins. in diameter, with appropriately lettered brass cap leaded into the top, having a hole drilled in it to mark the range line; the monument to be so set that this cap, serving as a level bench, is just below the pavement and protected by a loose brick or tile.

Coming now to the expense side of the question, the iron monument has greatly the advantage, costing only $2 or $2 25 each, as compared with more than double these figures for the marble, even though in the latter the cheapest grade of stone be used (Sutherland Falls, $1 70 per cubic foot in Philadelphia). It may be added here that this Sutherland Falls marble is really better for range stones than the finer grades, for though it has not the whiteness and clearness of the cost-

lier stone, it has the more important advantages of much greater hardness and durability, besides being absolutely unaffected by frost. Of course this rule of the cheapest being best would not apply to granite monuments, as the cheaper grades of this stone are soft and liable to splinter.

On the whole the writer is hardly prepared to make a choice between the marble monument and the iron one applicable to all cases. In his judgment the former, looked at in the light of a monument only, is the better, having the advantages of weight, durability and the wedging effect of the earth, yet when it is considered that it will cost at least double as much as the cast-iron monument, it seems almost that the choice must be with the latter. The opinions of others on this subject would be very acceptable.

In conclusion, no matter what system of monuments is adopted, it should be the best of the kind obtainable. It is bad policy for any city to practice too much economy in the way of street monuments, and when the annoyance and occasional legal complication that is prevented by proper street marking is taken into account, no doubt remains of this; no stronger testimonial of the need for proper street marking can be found than the replies received from city engineers of cities unfortunately not so provided.

DISCUSSION.

Horace Andrews, M. Am. Soc. C. E. (by letter).—Mr. Broomall has described the method of marking points of reference in various cities. It would appear that everywhere, except at Salem, Ore., the marks are merely surface ones. The most durable marks are those buried underground, such as are used for marking trigonometrical stations. In such cases surface marks should be used also.* In trigonometrical work, if either mark is omitted, it is apt to be the surface mark. Under such circumstances, I have found underground marks in excellent condition after 20 years; it is self-evident, however, that they may be very difficult to find.†

Where surface and underground marks are both used it is customary to place the latter vertically below the former. In this position the underground mark is so inaccesible, where the surface mark is a

* See U. S. C. S. Report for 1868, pp. 113-14-15. Report by Richard D. Cutts, Assistant.
† Science, Vol. I, pp. 269, 394, 458.

monument 3 or 4 ft. long, that, in city surveys, it would not often be referred to. To obviate this inconvenience, eccentric underground marks, in addition to the one at center, are very useful.*

I have recently had occasion to use a stone monument placed on the north boundary of the city of Albany in 1800, by Simeon De Witt. This stone is in an excellent state of preservation, but it is so much out of plumb that the center is very indefinite. In this case, the soil, which is of fine sand, has been blown from around the monument. Many other stone monuments in this city, set to mark the city line, are equally indefinite. While I recognize the fact that, from practical reasons, city monuments must be, in general, surface marks, it seems very desirable that important fundamental points should also have underground marks.

Some of the chief reasons for neglecting to mark reference points for city work are due to the time, labor and expense involved. The Albany monument, referred to by Mr. Broomall, is designed to reduce these objections to a minimum. It is light, weighing 50 lbs. only, for the 3-in. monument, showing a 4-in. brass cap on the surface. It can therefore be readily carried by one man or transported on street cars. It is strong and durable and can be conveniently set with a post-hole auger, with a light bar where necessary. The 3-in. monuments, with brass caps weighing 1 lb. 12 oz., purchased in a lot of 50, have cost $1 95 each. The 3-in., double-hubbed, 5-ft. soil pipe is generally the most suitable in size. Iron soil pipes can, however, be obtained of a great variety of sizes from almost any dealer in plumbers' supplies, so that size and cost can always be adapted to the requirements.

According to my experience, monuments to be stable should be set in holes of small diameter, dug, if possible, with a post-hole auger, otherwise with a crowbar, and the spoon shovel generally employed by telegraph linemen. If the soil is very loose, and the trouble and expense can be afforded, the stability of the monument may be much increased by filling around it with concrete. This plan was that finally adopted on the New York State Survey. If a long trench is dug, the monument is very liable to lean in the direction of the trench after a while. It is very inadvisable to attempt to set monuments with tools that are not suitable for digging a small, deep hole.

Malicious or mischievous interference is more to be feared than the natural disturbing action of the elements. I have seen the surface marks of a primary trigonometrical station nearly destroyed by fires, apparently made for that purpose; others I have seen battered to pieces with stones. The brass caps of the Albany monuments have occasionally been removed by means of fires built to melt the lead jointing, or by pounding them in. Such destruction is only to be feared in the suburbs, where the monuments may advantageously be

* New York State Survey Report for 1887, Appendix B.

buried, if their positions are suitably referenced. Surveyors in Albany have sometimes used pieces of old rails, 6 to 8 ft. long, with a cross marked on the end; these are admirably adapted to withstand hard usage, and are very suitable for newly laid-out streets.

I have found it difficult to adhere to rigid rules regarding location. In suburban places, where the houses are apt to be built back of the street lines, the street corner is the best and most convenient place for the monument. At other places the monument can be set near a corner, on one street line and 3 or 5 ft. from the other. In this position an instrument can be set directly over the monument, and can sight past the stoops of houses, which are tolerated in Albany where not projecting more than 8 ft. At too great a distance from the corner, sewers, gas and water pipes, when laid under the sidewalks, will be liable to disturb the monument. A location at the center lines of streets would seem to be in the greatest danger of disturbance.

The German practice in marking reference points is instructive. Sometimes the mark is a triangle cut on one vertical face of a monument.* Round monuments, moulded from cement, with lettering around the monument, have been used in Stuttgart, the monument having a spherical top to serve as a bench mark.† An example of some of the excellent referencing of trigonometrical points in Baden is given in "Das Deutsche Vermessungswesen," Vol. I, page 272. Pieces of agricultural tile are extensively used, and suitable "earth borers" are figured in German instrument catalogues. Sometimes a wide hole 1 ft. deep is dug, and the tile is set vertically in the bottom of the hole, by digging to an additional depth with the "earth borer." The bore of the tile is useful for receiving the sighting pole; a hole for this purpose being, indeed, generally made in the stone and iron monuments. After the completion of the survey, a stone monument of moderate size and cost is placed over the tile, the shallow hole then being filled up.

In detailed surveys of cities long built up, the problem consists in the accurate location of buildings which in themselves are monuments, and the only ones giving the street lines. In the very detailed survey of the city of Berlin, monuments are little used; crosses cut in the curb or sidewalks are of temporary service, and are so well and carefully measured from adjacent building corners that their location can be reproduced with precision. Attempts are frequently made, however, to mark the traverse points in old cities where the traffic is great and the possibility of disturbance is considerable. The best method of such marking that I have seen described is that devised by Mr. Gerke‡ for use in the city of Altenberg,§ a modification of that previ-

*Jordan, Vermess. Vol. I, p. 307. 1877.

† Zeitschrift fur Vermessungswesen. 1872.

‡ Zeitschrift fur Vermess. 1871, p. 197, etc.

§ Also employed by Mr. Nagel, in Leipsic.

ously used by him. Mr. Gerke summarizes the demands for the proper marking of points in the interior of cities as follows:

(1) Durable, solid material, not liable to danger from frost or decay.

(2) Secure placing and the selection of an easily found surface mark.

(3) The mark itself must not be buried and must be adapted for holding a sighting pole.

(4) A surrounding case must be used to guard against danger from repaving or disturbance. This case must be capable of lateral or vertical shifting without affecting the mark.

To answer the above requirements Mr. Gerke uses a cast-iron pin 60 cm. long, 8 cm. square on top, and 4 cm. square immediately above the point. The pin has a rounded top with a tapering hole about 3 cm. in diameter and 17 cm. deep, to receive the sighting pole. These pins weigh 14 kgr. and are driven into the paved streets with their tops 15 to 20 cm. below the surface. A small octagonal iron box, with lid held on by lugs and requiring to be turned with a key, is placed over the pin. The top of the box is flush with the pavement, which latter rests on a flange formed on the bottom of the box and thus holds it securely. The box weighs 16.5 kgr. Box and pin together cost about $1 10, which Mr. Gerke justly remarks is extremely cheap. The tops of Mr. Gerke's iron pins are designed to serve as subordinate bench marks. For bench marks of importance there are round-headed bolts cemented into holes drilled into the walls of houses in many German cities. The initial bench mark of Prussian surveys is of enameled glass inlaid in a block of granite in the wall of the Royal Observatory at Berlin. It has a millimeter division, running 10 cm. each way from the central mark, which latter is 37 m. above the normal zero. This scale is protected by a metal box with a locked door, the whole arrangement being quite ornamental in appearance. An agate topped bolt in the foundations of another part of the building gives a means of guarding against possible loss of the enameled scale.

For absolute security, an initial datum plane might well be referred to not less than three bench marks, such as are described by Mr. George W. Cooley, in the *Transactions* of the American Society of Civil Engineers for 1889. I am of the opinion that such bench marks would be preferable to marks made on the walls of buildings under most conditions, and with foundations that are heavily loaded. Mr. Cooley's bench marks are beyond the influence of frost; they cannot settle into the ground from insecure foundations, as many buildings are known to, and they would not seem to be liable to disturbance from earthworms, a danger indicated by Darwin.

C. M. Broomall, Jun. Am. Soc. C. E.—The description given by Mr. Andrews of the cement monument used in Stuttgart is very

interesting, and such a monument, if its durability could be insured, ought to be a good one. It would seem to the writer, however, that there would be danger of its going to pieces. This might be prevented if the cap could be so made as to cover and enclose the upper 6 or 8 ins. of the monument, being held by iron rods, or other means, to the mass of cement below. For the fullest application of this monument it would be necessary to have it so that it could be made *in situ*, the hole being dug of proper size and filled with cement and the cap then attached and centered before the cement had hardened. The details of this attachment would have to be such as to make it firm and lasting.

In regard to the buildings becoming monuments in the built-up portions of cities, this is true to a certain extent; but when it comes to making use of them for the protection of streets into unmarked territory they would seem to be of questionable use unless cumbersome and detail notes were preserved of the exact location of some properly defined point on each "range" house. Unless these defined points were regularly prepared and marked in the wall of each house, and on some definite system of lines, a great loss of simplicity would result, making lengthy extracts from the city plan necessary for every piece of work.

The use of several initial level benches is to be recommended. If this is not done it might result in the state of things existing in the writer's town, where the datum stone, the basis of all levels, originally situate in an adjacent valley, has become washed away. As the local range stones have been more or less subject to natural changes as time passed, the consequence is that when any extensive leveling operations are undertaken it is necessary to do an amount of averaging up that is anything but satisfactory.

It is much to be regretted that the question of street monuments is not separable from the money side of the matter. The kind and extent of monuments is not only dependent upon mechanical principles, but is almost equally dependent upon the amount of money the authorities are willing to expend, which is not large. Since the stones are lost from time to time and the engineer is not, as a rule, authorized to replace them, there is developed a strong tendency toward decline, which is seldom successfully resisted. It is only when things have gone so far that something must be done that the city authorities see the false economy of their action.

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(Vol. XXXII.—July, 1894.)

THE LOAD LINE IN TELEPHONE EXCHANGES.

By A. V. ABBOTT, Jun. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

A study of the variations in loading to which dynamic plants are subjected forms one of the most interesting of engineering investigations. The station loads carried by electric and cable railway plants have, during the past few years, formed a prolific topic of scientific discussion, and the results have revolutionized certain departments in steam engineering. Similarly, the managers of electric light plants are perpetually seeking to realize a maximum output with a minimum of invested capital and operating expense.

Among interesting load lines, those presented by the daily burden on telephone exchanges exhibit some features of peculiar interest, well worthy of professional consideration. The telephone exchange is merely the mechanism whereby different parties may be rapidly and reliably placed in talking relations with each other, and the exchange only fulfills its office in proportion to the efficiency with which this

end is accomplished. Considering that some of the larger exchanges in this country are handling messages at the rate of 100 000 000 a year, the importance of a consideration of the exchange load line becomes apparent.

Before passing to the actual examination of the load line proper, it will be pertinent to look at the principal and essential features of the exchange system, in order that the relation of the load line to the apparatus and methods of operating may be fully appreciated.

A telephone exchange consists of one or more offices, in which the switching apparatus for placing subscribers into intercommunication is located. The simplest exchange consists of a single office into which the lines from all subscribers converge. Such an office is always the commencement of any telephone exchange, and is, naturally, located as near as possible to the electrical center of gravity of the subscribers' district. As business increases and additional subscribers are connected with the exchange the territory served enlarges, and a point is soon reached when the line mileage from the varying subscribers to the central office becomes an important consideration.

As in any exchange the actual number of subscribers in conversation at any one instant is comparatively a small proportion of the entire number served, territorial dimensions soon indicate the advisability of establishing a branch office, into which the more distant subscribers may be carried, the switchboard of which shall be connected with the original central office by means of a small number of trunk cables that are sufficient to serve the maximum number of subscribers that are likely to be in conversation at any single instant. Thus, in the largest cities, the growth of the exchange is centrifugal, extending outward from the original central district. The telephone system has been very aptly compared to the nervous system of a sentient organism, in which the various outlying offices may be represented by the subordinate nervous ganglia—the main, or central, office occupying the place of the brain.

At each of the offices in an exchange, the appropriate apparatus for rapidly switching subscribers into talking relations must be located. This apparatus usually takes the form of a switchboard—a typical representation of which is indicated in Plate X.

Considering this, it is evident that the switchboard consists of vertical panels carrying the subscribers' switches, or spring-jacks

underneath which a shelf is located having a number of flexible cords terminating in metal plugs, the insertion of which into the spring-jacks of two respective subscribers places them in talking relations with each other. Directly beneath the cord shelf, manual keys are located, enabling the operator to place herself in communication with the various subscribers, and beneath the keys are located annunciators serving to notify the operator that a connection is desired.

The manipulation of the switchboard will be more clearly understood by reference to some of the electrical features, as contained in the circuit common to the so-called standard switchboard, shown in Fig. 1.

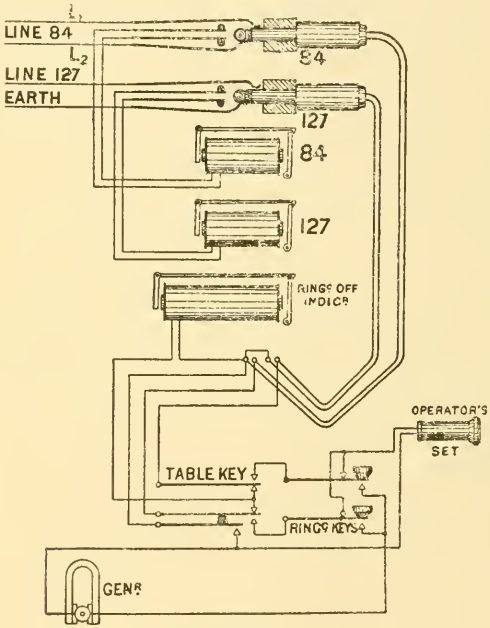


Fig. 1.

The diagram illustrates two subscribers, Nos. 127 and 84, in conversation. Imagining for a moment that the plugs introduced into Nos. 84 and 127 are withdrawn, it will be seen that one side of the line of each subscriber enters the spring-jack at the exchange, and, passing through the jack, runs to an annunciator bearing the appropriate subscriber's number. The other side of the line leaves the annunciator through

the spring-jack, and returns to the subscriber. The electrical impulse produced by turning the crank of the subscriber's magneto passes through the spring-jack, thence to the annunciator, allowing the shutter to fall and disclosing the appropriate number. Upon noticing the falling annunciator shutter, the operator lifts one of the plugs attached to the flexible cords in front of her, and places it in the spring-jack bearing the number corresponding to that disclosed by the annunciator. At the same time she presses the table key, thus connecting her telephone with the subscriber's line. Examining the diagram in Fig. 1, it will be seen that the introduction of the plug in the spring-jack lifts the springs of the jack in such a manner as to disconnect the annunciator and, at the same time, connect the operator's talking set from the table key with the subscriber's line. When the order is received, the operator lifts the companion plug of the one first inserted, placing it in the spring-jack of the subscriber with whom conversation is desired; simultaneously, she presses the ringing key, thus sending an impulse through the line of the called subscriber, causing his magneto to sound. As soon as the called subscriber answers, the operator releases the table keys, thus cutting her telephone out of circuit and placing the two subscribers in private talking relations. In the diagram, it will also be noticed that a ring-off indicator, or "clearing-out drop," as it is usually called, is placed as a shunt across the pair of cords connecting the two subscribers. As this indicator is wound to have a large impedance, it but very slightly shunts the rapidly alternating telephonic waves, but is readily sensitive to the slower alternations of the magneto current. Thus, at the close of conversation, a turn or two of the subscriber's magneto is sufficient to throw the clearing-out drop, indicating to the operator that conversation is terminated and advising her of the necessity of the withdrawal of the cords and plugs. A circuit of this kind is in use only in the smaller exchanges, where each subscriber's line is supplied only with a single spring-jack and is readily in sight of the operators; the mere presence of the plug in the spring-jack serving to indicate that the line is engaged and debarring the operator from interrupting a conversation already in progress by the attempt to connect either of the talking subscribers with any other party that may desire connection with them.

Experience has shown that a single operator can rarely attend to

more than 100 subscribers, and in the more busy exchanges from 50 to 60 is usually all that can be adequately served. Thus, in large exchanges the proportions of the switchboard would soon place a large number of the subscribers out of sight and out of reach of many of the operators working a switchboard constructed upon the lines indicated. It is, then, customary to have recourse to the multiple switchboard, in which the line of each subscriber, instead of being extended to a single spring-jack, is placed in series through a number of jacks so arranged that each operator has access to a jack connected to the line of every subscriber. The outline of such a circuit is indicated in Fig. 2, showing the location of a number of

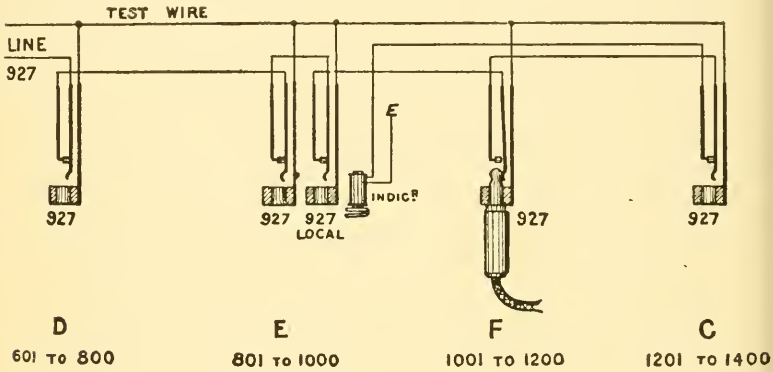


FIG. 2.

operators—*D*, *E*, *F* and *G*—in front of each of which a single line is multipled by passing through an equal number of spring-jacks set in series with each other. By such an arrangement, it is evident that any operator may readily reach all of the subscribers in the exchange. This method, however, requires additional apparatus in the circuit, to provide the operator with a means of ascertaining whether a line is engaged or not. This is accomplished by means of the "busy test" method, which consists in providing a local battery in every cord circuit. This cord circuit is shown in Fig. 3. Here it will be noticed that the sleeve of the plug is connected to the earth through a resistance coil and a small battery. When the plug is inserted in the spring-jack (see Fig. 2) the battery is placed in electrical contact with the jack ring. It will also be seen that the center of the operator's telephone is connected to ground, and the operators are instructed to touch, with

the tip of the plug, the ring of the subscriber's jack with which connection is desired. By tracing the circuits, it is apparent that the insertion of the plug places battery upon the rings of all the jacks on each line which is engaged in talking, and, by touching any ring with the tip of the plug, the operator, if the line is engaged, will hear a sharp click in her telephone, thus notifying her of the fact that the line in question is under conversation.

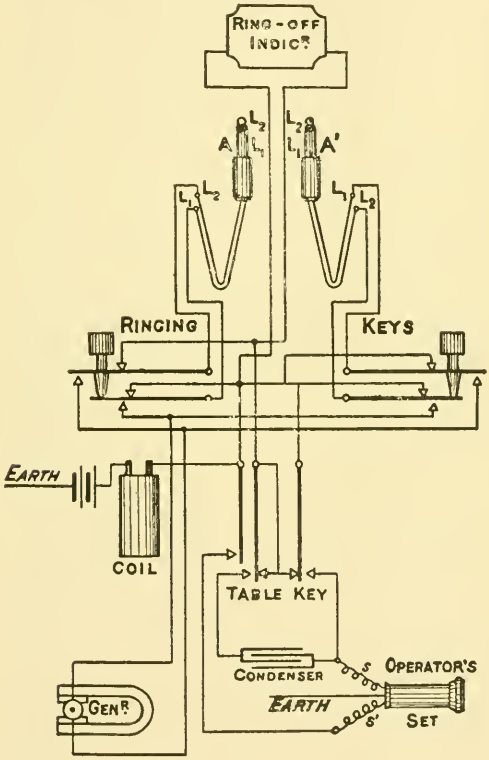


FIG. 3.

The shape of the load line in any exchange is evidently governed partly by the speed and facility with which the operators are enabled to perform the various evolutions described as necessary to make connections between subscribers, and partly by the nature of the business done by the exchange. The work done by the operator thus becomes an important governing factor in the load line.

Fig. 4 is a diagram representing the time occupied by the operator in performing the various functions necessary to complete a connection. These results are derived from investigations made upon the Cortlandt Street office of the New York exchange.

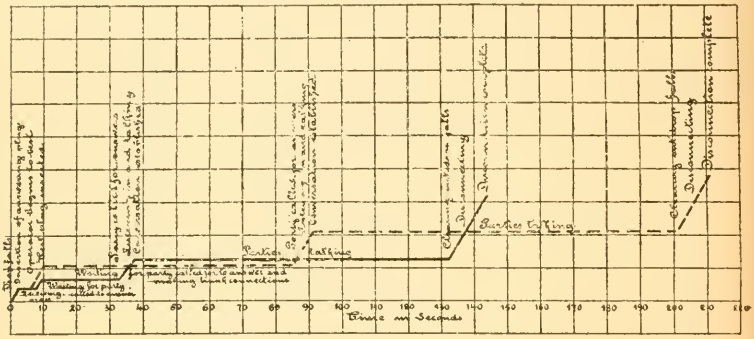
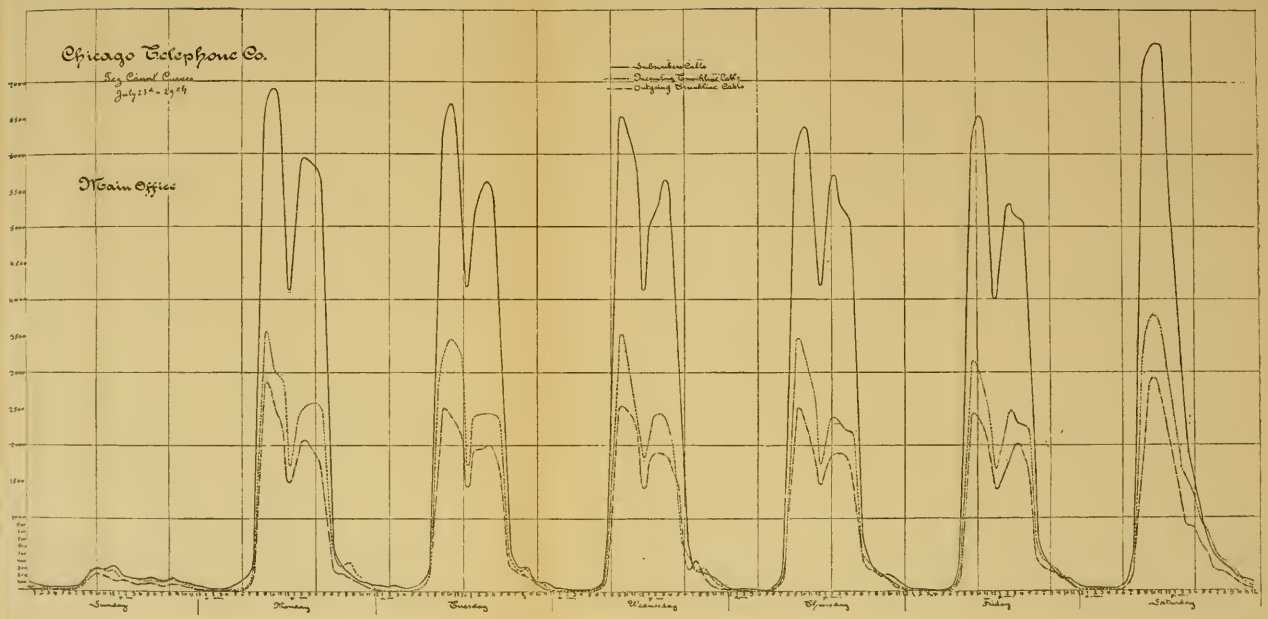


FIG. 4.

The axis of X in the diagram is taken to represent intervals of time. The fall of the drop is assumed at zero time. A little over two seconds are occupied by the operator in inserting the answering plug. Six seconds are consumed in obtaining the subscriber's order and in testing the desired line to ascertain whether it is engaged or not. About 23 seconds are exhausted in obtaining an answer from the called subscriber, while about five seconds more are expended in seeing that the connection between the two subscribers is fully completed, and that conversation has been initiated.

About 97 seconds seems to be the average of most conversations and about 10 seconds more suffice to receive the clearing-out signal and disconnect the parties, leaving the lines ready for another call. Such is, diagrammatically, the history of the operations and time expended in completing the average local conversation between two subscribers extending into a single office.

The business of the exchange is still further complicated by the frequent necessity of trunking calls between outlying offices, for, as already indicated, the growth of the exchange soon leads to the establishment of a number of branch offices connected between themselves and to the original center by means of trunk cables. When a message proceeds through two offices, it must of necessity pass through the hands of two operators and through two switchboards. To accomplish


Chicago Telephone Co.
Reg. Circuit Curves
July 21st - 27th
Main Office
Subscriber Calls
Incoming Trunk Calls
Outgoing Trunk Calls
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday

the business thus transferred, it is customary to locate in front of every operator a certain number of trunk lines extending to all the other offices in the exchange. At the receiving end the trunks from the through offices are brought to special sections of the switchboard devoted to trunking business alone. In the trunking sections no subscriber's drops are placed, the attention of the incoming trunk operators being devoted entirely to receiving connections over the trunk lines and completing them on the multiple located in front of them. In Fig. 4 the dotted line illustrates the time consumed in calls which are trunked between offices. Thus, starting from the origin, a little little longer time is consumed in inserting the test plug, for the reason that the operation of testing trunk lines is rather slower than that occupied in subscriber's lines, as it usually happens that several of the trunks are engaged and a number of lines have to be tested in order to find one which is free.

In the local connection the party called for answers in about 33 seconds, while in the trunk connection some 85 seconds are consumed in passing through the second office and in obtaining an answer from the party called for. For this curve, also, it would appear that trunk conversations last a little longer than ordinary local calls. The operation of disconnecting, however, seems to be performed with equal rapidity.

To determine the load line, it is now customary in nearly all the larger American exchanges to make frequent tests of the amount of business. To this end, recourse is had to what is termed "operator's peg count." In front of each operator is placed a panel containing the subscribers' spring-jacks, each one bearing an appropriate number. The operator is supplied with a wooden peg, which at the commencement of the count she inserts in jack 0. As fast as calls are received she moves the wooden peg from hole to hole, counting calls something after the fashion of a cribbage board. At the end of each hour, the superintendents in the operating-room note the position of the peg, thus determining the number of calls which have been received by the individual operators. At the end of the day, the sheets bearing the facts thus obtained are tabulated and the results plotted in a convenient form for inspection.

Plate XI is a chart of the business transacted in a week by the main office of the Chicago Telephone Company. At the time this count

was made, this office embraced about 5 000 subscribers, while the entire exchange numbered some 10 offices, including about 10 000 subscribers.

In the diagram, the vertical axis indicates the number of calls made, while the horizontal axis is divided into hours throughout the whole week. The diagram commences at midnight on Sunday and extends to midnight on the succeeding Saturday. The full lines in the diagram indicate the subscribers' calls which are made and completed in the office under consideration. The fine dotted line indicates the incoming trunk line calls, namely, those calls which originate in subscribers located in external offices, and which are trunked into the main office, while the broken dotted line indicates the outgoing trunk calls, that is to say, those calls which are received by subscribers in the main office and which are not completed there, but are trunked to subscribers located in some of the outlying offices. From midnight to 7 o'clock on Sunday morning, little business was done by the exchange, the number of calls in any one hour barely reaching 100. From 7 to 10, the business steadily increased, reaching at 10 o'clock a maximum of about 350 calls per hour. Another maximum occurs between 12 and 1, reaching about 375 calls. From this point the business steadily decreases, reaching a minimum between 2 and 3 on Monday morning. From 3 o'clock to about 7, there is a slight increase. At 7 o'clock the business of the day begins, the number of calls rising rapidly from 200 per hour at 7 o'clock to a maximum of 6 920 calls an hour at about 10.15. From 10.15 to 12.30, the business decreases, being reduced to 4 150 calls per hour during lunch time. From 12.30 to 2.15, the business again increases, reaching a second maximum of 5 950 calls. From this point a rapid decrease is observed, to the rate of about 500 calls an hour between 7 and 8 o'clock in the evening. The curve at this point turns and slowly decreases again until about midnight.

Between 2 and 3 o'clock, a slight increase is observed, due to newspaper business, while the minimum of the entire 24 hours is reached at 4 A.M., at a rate of about 50 calls an hour. Comparing the business of the successive days in the week, it will be observed that rather more business is done on Monday than any of the succeeding days, with the exception of Saturday. During Tuesday, Wednesday and Thursday, the business decreases, reaching a minimum on Thursday. On Friday,

Harrison Office
Oakland Office
Canal Office
South Office
West Office
Main Office

a slight increase is observed, while on Saturday the effect of the summer half holiday is plainly marked. Here, it is evident that an effort has been made to transact the entire business of the day in the forenoon, the maximum being reached at 11 A.M., with a rate of about 7 650 calls an hour. From 11 A.M., the business drops sharply, there being no indication of any noon hour, but the holiday effect is also noticeable in the increased number of calls which are made during the evening hours, from 6 to 9 o'clock. While the chart thus given may be considered a typical representation of a week's business, it is necessary to take carefully into account the modifying effects of the general state of business in the city, the effect of any unusual occurrence, such as holidays, large fires, railway accidents, or other contingencies, and, particularly, the state of the weather. Thus, during the summer time, especially in the midsummer months, the business of the exchange is liable to fall off, owing to general slackness from vacation time, and also due to fine weather making pedestrianism attractive. Conversely, in the winter time, when business is more brisk, or when stormy weather is conducive to office confinement, the business of the exchange may rise enormously.

A study of the load line, however, is more particularly advantageous in adjusting the operating force to the business of the exchange in a way to make the quantity and quality of the service a maximum with a minimum of operating expense.

In Plate XII some curves are given of the main office in the Chicago exchange, together with five of the outlying offices. These curves were plotted from results obtained in July, 1893. The arrangement of the curve is a little different from that of the preceding diagram, that is to say, connections which originate and are completed in the same office are plotted in full in heavy line on the right-hand side of the diagram, while the incoming trunk calls are indicated in a similar manner by a heavy line on the left-hand side of the diagram. In the diagram on the right, out-going trunk calls are indicated by the broken dotted line, while on both curves the number of operators required to transact the business given by the full curve is indicated by the fine dotted line. There seems hardly to be such a parallelism between these two lines as the most efficient service would indicate. However, in adjusting the number of operators to the business transacted, it must be recollected that it is impossible to decrease

the operating force precisely in accordance with the service demands. The operator is necessarily a unit, and one of considerable magnitude, particularly when considered in proportion to a single call. Thus, to serve half a dozen subscribers will require one operator, while 100 could be served with equal facility. As it is impossible to subdivide the individual operator in proportion to the business to be transacted, there occurs a great discrepancy between the force line and the load line in certain parts of the diagram.

At night time, for example, the number of operators rises far above the actual force which could transact the business. It is essential to watch the entire switchboard, as an occasional call may come in upon any section, and, as the switchboard in the office under consideration is nearly 200 ft. in length, quite a large operating force is required, simply for supervision, irrespective of the number of calls to be answered. It is also impracticable to change the working hours of the force in a manner to coincide exactly with the variations in the business. While this can be done to some extent, it will cause only a partial agreement between the force line and load line. As an example, however, of what has been done in this direction, as developed by a study of exchange load lines, refer to Plate XIII.

In Plate XIII 6 900 calls were handled with 82 operators.

In Plate XIII 8 450 calls were handled with a maximum force at any time of 72 operators, while the whole force line indicates a number in closer agreement with the load line.

A similar change may be seen, by comparing the load and force diagrams of the Harrison office, Oakland office, South office and West office Taking the whole exchange in the time intervening between the two peg counts, which are here charted, the business increased about 8%, upwards of 1 000 000 additional messages a month, while the operating force was decreased some 18%, with marked improvement in the quality of the service attained.

It is also curious to note the effect on the load line of the kind of district in which the exchange is located. Thus, in the load line for Harrison office, it will be noticed that almost no business is done after 8 o'clock P. M., while in South office, between 7 and 8 P. M., a maximum occurs of nearly 600 calls an hour. This is explainable when it is considered that the Harrison office is located in a district which is exclusively a large business district, the offices of which uniformly close

PLATE XIII.
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between 5 and 6 P. M., while in the case of South office, the district is to a great extent a residence one, and the maximum indicated between 7 and 8 o'clock is caused by the formation of evening appointments.

In a like manner the study of such load lines forms an exceedingly valuable source of information in the location of branch exchanges and the distribution of subscribers' lines. The trunking of calls between branch offices has already been alluded to. It is quite evident that the establishment of branch exchanges increases the cost of operating, as it requires the expense of additional buildings, additional supervision and a general increase in the non-productive portion of operating expenses. Where, by means of a branch exchange the capital invested in the subscribers' lines may be decreased by shortening those lines, resulting in such a saving as to warrant the increase in operating expenses, a branch exchange becomes profitable. On the contrary, if the business in the district covered by the branch exchange is of such a nature as must necessarily come to the main office, the establishment of a branch exchange must be supplemented by such a large number of trunk lines as practically to extend the line of each subscriber into the main office. Thus, under such circumstances, the establishment of a branch exchange becomes an impediment rather than an assistance, as the speed of the service is reduced, greater expense is incurred, and no particular saving can be made in the capital expended. For example, in the Harrison office, in both of the diagrams here given, it will be seen that the outgoing trunk calls amount to a very large proportion of the entire business of the office; actually in some cases, instances rising to from 85 to 95% of the entire business of the office. A careful analysis of the business done by the Harrison office indicates that such a large proportion of the work was trunked through to the main office as to make the establishment of the Harrison office, viewed simply from the standpoint of operating expense, not fully justified. By a careful re-arrangement of the subscribers in the Harrison office, this proportion of trunking has been very largely modified, so that at the present time not over 60 to 70% of the business done by the Harrison office is trunked out of it. As a comparison, refer to the curves of the main office, in which it is seen that of the total business originating in the main office, only about 30% is trunked out of it.

Such are some of the more salient deductions to be drawn from a

study of telephonic load lines. The improvement in service which has resulted to the Chicago company during the past six months from investigations of this description, has been so marked that a regular system of peg counting now forms one of the features of the operative service of the company, regular counts being made on the tenth of each month. A special count takes place whenever circumstances of so peculiar a nature arise as to seem worthy of investigation.

Exchanges in New York and Boston are following a similar course, deriving like advantages from the information thus obtained, and by means of an interchange of curves between the different exchanges the amount of valuable information obtained is largely augmented.

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722.

(Vol. XXXII.—July, 1894.)

NOTES UPON TESTING BUILDING STONES.

By F. LYNWOOD GARRISON, Assoc. M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

Probably no one who has given the subject of testing building stones careful consideration is willing to admit that the methods now in vogue for determining the strength of structural material of this character are satisfactory or entirely reliable. This condition is probably due, as an eminent authority remarks, "to a lack of knowledge of the methods by which such tests can be made, and to a lack of appreciation of the necessity of such tests." * The old idea that one stone is as good as another as regards durability and strength cannot be too strongly condemned, since all stones or rocks are compound bodies, often exceedingly complex, composed of aggregations of various mineral substances whose individual nature and their respective influence upon one another should be understood as far as is possible, to arrive at a proper appreciation of the whole. This necessitates at least an elementary knowledge of mineralogy, geology and lithology, the study of which has unfortunately not been included in the training of most civil engineers and architects.

* Merrill. "Stones for Building and Decoration," p. 384.

In this connection the writer cannot do better than to quote the words of Dr. Alexis A. Julien in Vol. X of the Tenth Census of the United States.* "Hardly any department of technical science is so much neglected as that which embraces the study of the nature of stone, and all the varied resources of lithology in chemical, microscopical and physical methods of investigation, wonderfully developed within the last quarter century, have never yet been properly applied to the selection and protection of stone for building purposes." Although this was written a number of years ago, it is extremely doubtful if much improvement or progress has been made since, and engineers in general probably know little, if anything, more of the properties and peculiarities of the wonderful varieties of structural material so bountifully provided by Nature.

In presenting these notes for publication it is not the writer's desire to set up any system of testing building stone or to present any new scheme of his own, for, with possibly one exception, none of the methods or tests mentioned herein are in the least degree new or original. The sole aim of this paper is to emphasize the necessity and desirability of using, developing and improving the systems already established. A few years ago when attention was called to the utility of the microscope in the metallurgical investigations of iron and steel, many competent metallurgists doubted its practical value ; now, however, metallurgical literature teems with valuable papers upon the subject, and the practical value of the microscope in this branch of technical science has been fully established.

In the writer's opinion the practical value of microscopical examination of stone is much greater than that of ordinary metallurgical productions. In the one case we have a natural production about which we can know nothing without an investigation. In the other case we have an artificial material made for a distinct and definite purpose, to effect which we must needs know more or less of the characteristics and relative reactions of the individual elements constituting the desired compound.

The tests ordinarily applied to building stone, to determine its physical properties, although few in number, are in some instances rather complicated and often unreliable. The first and most essential is to determine the structure and character of a stone, to know whether it

* "Report on the Quarry Industry," p. 364.

be a granite, syenite, sandstone, quartzite or something else. Although an expert can usually determine at a glance to which, if any, of these groups a particular stone belongs, it is frequently possible to determine the precise lithological character only by a microscopical examination. Thus, for instance, there is a class of Cambrian rocks commonly called sandstones (Potsdam ?) that are not sandstones at all, but are hard, compact rocks known as quartzites, which have been derived from sandstones by metamorphic action. The essential difference between a sandstone and a quartzite lies in the presence of secondary silica between the quartz granules comprising the latter; the presence of this secondary silica or quartz can be determined for a certainty only by microscopical means. The microscope is not only useful in determining the structure of a stone, but it has an even greater practical value in making it possible to detect the presence of deleterious substances such as pyrite, and marcasite (iron sulphides) or other minerals whose chemical composition is affected by atmospheric agencies and thus exert a deleterious effect upon the stone. The application of the microscope to this, as to every other purpose, requires some skill and training, which may, however, be readily acquired by anyone to whom the subject is of sufficient interest, microlithology being thoroughly treated in standard works available to all.

Strength.—The character of a stone being established, it is usually desirable to determine its strength as a resistant to crushing, shearing and bending strains. Ordinarily the first is considered sufficient, but the determination of the second and at times the third is often more essential.

Form of Specimens.—In determining the compression strength of a stone, cubical specimens are usually prepared varying in size from 1 in. to 5 ins.; the dimensions of the cubes are important factors, since it has been found that the resistance increases in the ratio of the cube roots of the sides of the respective cubes expressed in inches.* More generally and with greater simplicity this law may be expressed thus: The strength of geometrically similar test pieces varies as the square of homologous sides.† Consequently a stone will develop its maximum resistance in the largest cubes.

* Gillmore. "Notes on the Compressive Resistance of Freestone, Cements, etc.," pp. 20–29.

† Unwin. "The Testing of Materials of Construction," p. 422. London, 1888.

Too much trouble cannot be taken in preparing the test cubes, the care with which it is done having a most important influence upon the result. When such small samples are dressed by hammer and chisel, they become filled to some extent with minute cracks, the number of which increases inversely with the size of the cube. If, however, the cube has been carefully sawn and ground down to the requisite dimensions, this weakness is avoided, or at least reduced to a minimum.

Cushions.—The faces of the cube, which come in contact with the compression plates of the testing machine, should be perfectly smooth and even, otherwise they must be provided with cushions of plaster of paris or some other material, which will avoid the superficial irregularities and produce a uniform bearing upon the compression plates. Baker states that "the nature of the material in contact with the stone while under pressure is a matter of great moment. If the materials which press upon the top and bottom of the specimens are soft and yielding and press out sideways, they introduce horizontal forces, which materially diminish the apparent crushing strength of the stone. If the pressing surfaces are hard and unyielding, the resistance of these surfaces adds considerable to the apparent strength." *

While these remarks would seem to lay undue stress upon a comparatively unimportant detail, it is, however, necessary in all cases to provide a uniform bearing between the compression plates and the specimen. Whenever possible, this bearing should be directly upon the specimen itself. The faces of the cube must, therefore, be perfectly smooth and parallel, and, when such is the case, irregularities in the results cannot be attributed to an imperfect artificial bed or bearing.

Bed or Natural Position.—Care should always be taken to determine whether the pressure is applied upon the bed of the stone or upon its edge, since a stone will always develop a maximum strength when the pressure is applied in a line perpendicular to its natural position or "grain." It is not always possible to determine the bedding of a rock from a mere inspection of a number of samples. Indeed, even at the quarry, in some instances, it may puzzle an experienced geologist to determine the original or natural horizontal bed of the rock if it be of a sedimentary origin, or a metamorphic rock, and when eruptive it may be quite impossible, although most, if not all, eruptive

* "Treatise on Masonry Construction." I. O. Baker, p. 6.

rocks have a tendency to break in certain directions or planes in which the cohesive power of the stone is weakest. This property may be considered as similar to the cleavage phenomenon of crystallized minerals, and for practical purposes when testing a stone these planes may be considered as the bed. This cleavage property can usually be detected in massive rocks, such as some of the granites, by experienced quarrymen.

In many metamorphic rocks the bedding is made very distinct by the distribution of the mica in such a manner that its laminæ are arranged in definite parallel planes, which impart a stratified appearance to the rock. When this stratification becomes marked, the stone is known as gneiss ("stratified granite"). With sandstones, and probably also with quartzites, the proper recognition of the bed or grain has another point of practical value, since such stone will not only weather better when laid upon its natural bed, because all sandstones most readily absorb moisture in the direction of their grain or bed, but it will withstand a greater amount of heat without disintegrating. This is an important fact in cities, where walls are apt to become highly heated in fires.

Fig. 1.

Fig. 2.

It is desirable that the pressure applied by the testing machine shall continue until the specimen is completely crushed into smaller pieces. The character of these fragments should be noted, as it has been observed that in the stronger stones there is a tendency, when the pressure is applied upon the bed, for these pieces to develop into pyramidal shapes with round edges (Fig. 1); whereas, in weaker samples

of probably the same stone, or if the pressure has been applied on the edge, for the fragments to assume an angular flaky character (Fig. 2).

Some stones will not assume either of these forms, but will crush or crumble into numerous small fragments of no particular shape.

Shearing Strength.—One of the most useful tests to which a stone can be subjected is that to determine its resistance to shearing strains. It is, moreover, a test seldom made, and a description of the method recently adopted by the writer may be of interest. It was required to determine the suitability of certain stone for street paving purposes, and while the determination of the stone's crushing strength was very useful, its resistance to shearing strains was deemed a factor of more practical value.

At the suggestion of Mr. Tinius Olsen, of Philadelphia, the well-known builder of testing machines, the writer had the stone test pieces made into rectangular blocks or slabs 1 in. in thickness, 2 ins. in breadth and 4 ins. in length. In making the tests, each stone block was securely clamped between two heavy cast-iron plates made especially for the purpose. The center of each of these plates was provided with a rectangular slot 1 in. wide by 2½ ins. long, whose sides had been carefully machined and were perfectly smooth. The stone test piece was placed so as to cover the slot in each of the plates, which were then clamped together and the specimen held in place by two screw bolts passing through the iron plates. In this way both ends of the specimen were supported; then, by inserting a steel block or punch into the slot of the upper plate and applying the pressure, it was possible to shear or punch out a section of the specimen 2 x 1 x 1 ins., thus subjecting the stone to no other than a shearing strain.

The results of four tests made in this way upon hard quartzite blocks are given in the following table:

	Size, width and thickness.	Area. Square inches.	Broke at. Pounds.	Strain per square inch. Pounds.
No. 1.....	2.027 1.020	2.067 x 2 = 4.134	28 930	6 990
No. 2.....	2.032 .994	2.019 x 2 = 4.038	9 600	2 370
No. 3	1.990 1.038	2.065 x 2 = 4.130	22 980	5 560
No. 4.....	1.990 .930	1.850 x 2 = 3.700	23 550	6 360

A number of tests made upon cubes of the same material is given in the next table. In this case the shearing tests were made by clamping one-half of the block between the bearing blocks of the machine and then applying the load to the upper face of the projecting half, the bottom being unsupported, until it was shorn off.

A bending strain is undoubtedly introduced in this case, and the results were by no means satisfactory, as a comparison of the tables will show; in the former case they were from two to five times higher.

SHEARING TESTS OF 2-IN. QUARTZITE CUBES.

No. of specimen.	Size.	Total shear in pounds for entire section of 4 sq. ins.	Shear per square inch, in pounds.	
7 871..... ...	2 x 2 ins. = 4 sq. ins.	7 400	1 850	Stone;
7 872.....	2 x 2 ins. = 4 "	7 600	1 150	average,
7 873.....	2 x 2 ins. = 4 "	4 000	1 000	1 481
7 874.....	2 x 2 ins. = 4 "	7 700	1 925	

A system of testing somewhat similar to the one adopted by the writer was used some years ago by Colonel Thomas Casey upon concrete intended for the Washington monument. The samples consisted of blocks 27 x 27 x 8 ins. thick, and were sheared by means of a cast-iron die 24 x 24 ins., provided in the center with a slot 10 x 10 ins. By means of a cast-iron punch, having a face area of 8.1 x 8.2 ins., and by placing the specimen upon this die, a section could be punched or sheared out through the slot.*

Another, and even simpler, method is to provide stone slabs 12 ins. long, 4 ins. thick and 6 ins. wide. These were tested by placing supports at either end of the sample 6 ins. apart. By means of a plunger, the area of whose face was 30 sq. ins., a section of the specimen between the supports could be sheared out.† It is, evidently, only possible to test such large specimens in an exceptionally large testing machine like that at the Watertown Arsenal.

Transverse Strength.—The determination of the transverse strength of a stone is sometimes important when it is to be used for lintels, sidewalks, culverts, etc., but since such a test involves a number of

* "Report of Tests on the Strength of Structural Materials Made at Watertown Arsenal, 1883," p. 222.

† "Tests of Metals, Etc.," U. S. Ordnance Department, Washington, 1891, p. 737.

factors which must be taken into consideration, the writer has as yet failed to discover a satisfactory method of arriving at the result desired. It seems to him that for all practical purposes a shearing test as just described would be all required.*

Elasticity.—Tests to determine the elastic limit, coefficient of elasticity and "set" are seldom applied to building stone. Probably the simplest method of determining these factors is the best, namely, by the attachment to the testing machine, when making the compression tests, of a suitable apparatus for recording the strains autographically. In this way it is possible to obtain a strain sheet from which the desired factors can be determined readily. A description of the apparatus used for this purpose upon the Olsen or any other testing machine would occupy too much space in this paper.

Porosity.—The porosity or degree with which a stone absorbs moisture is a test of the utmost importance, since, other things being equal, the less moisture a stone absorbs the better it is.

To determine this absorptive power the specimen should be thoroughly dried at about 100° Fahr. and carefully weighed; it must then be soaked for at least 24 hours in distilled water; when removed from the water, the surface allowed to dry in the air and then weighed. The increase in weight will be the amount of water absorbed, and will stand, although not absolutely correct, as an expression of the stone's absorptive power. This test is extremely simple, and when done with care should be entirely satisfactory and practically valuable. The absorptive power of rocks varies very greatly; in general, the sedimentary rocks, limestones, etc., are the most porous, and the eruptive rocks the least. The porosity of sandstones is characteristically exhibited in their manner of drying after a rain; some dry rapidly, while others retain their moisture a long time. Ordinary sandstones absorb from 3 to 10% of weight of water in 24 hours, the harder stones absorb much less.

Action of Frost.—Of all the atmospheric agencies liable to affect building stone frost is the most objectionable. Usually its deleterious effect varies in direct proportion to the porosity; it seems obvious that a stone which absorbs the most water will be the most liable to disin-

* Baker in his "Treatise on Masonry Construction," p. 11, gives a formula for calculating the transverse strength of stone slabs which may be found useful. It must be confessed, however, he has not treated the subject as clearly as might be desired.

tegration due to the expansive action of the ice formed in its interstices.

There are a number of methods in vogue for determining the effect of frost upon stone samples; they all consist substantially of various methods of alternate freezing and thawing, after which the specimens are washed, dried and given a final weighing. The loss of weight is an index of the durability in this particular.

Specific Gravity.—The weight or specific gravity is one of the most, if not the most, important factors in determining the value of a building stone, since by such a test we can also approximately determine its relative density and durability.

Hardness.—The resistance to abrasion or hardness of a stone is, perhaps, as easily determined by the method of Bauschinger as by any other.* It consists essentially in placing a block of stone upon a horizontally revolving cast-iron plate covered with emery, the stone being, of course, held in one position and loaded with weights if desired. The speed of the plate, the size of the specimen and the pressure upon it should, of course, be constant. By weighing the specimen at certain intervals its relative resistance to abrasion may be easily noted.

Destructive Agents.—The destructive influences to which a building stone is subjected may be divided into two general classes—mechanical and chemical. Of the former agencies the most potent in this climate are frost, rain and wind. The degree with which rain affects a stone's durability depends more upon the solvent action of the gases it may contain than upon the mechanical wear of the falling drops. Thus in large cities or in the vicinity of certain manufacturing establishments this solvent action is greatest, and may, in some instances, have a serious result.

The destructive chemical agents are, of course, not as energetic in dry as in wet weather. They are chiefly gases, ammoniacal, sulphuric and carbonic, resulting from the decomposition of organic matter, products of combustion, certain metallurgical operations, etc.

The only way to determine the effect of these gases upon any particular stone is to either subject it for a specific length of time to the direct action of the gases themselves, and noting their action and the stone's loss in weight, or to soak it for several days in water containing

* "Mitth. aus dem Mec. Tech. Laboratorium in München." Unwin, "Testing of Materials of Construction," p. 429.

the alkalies or acids corresponding to each particular gas. By noting the weight from time to time a fairly correct idea of the relative solvent action of the gases may thus be obtained.

Chemical Tests.—The chemical composition of a stone gives but little indication of its practical value, and the time, money and trouble spent in making the analyses is generally used to little purpose. It is, however, sometimes well to know the quantity of silica, lime and alkalies a stone may contain, since, other things being equal, silicious stones are the most durable. A sufficient knowledge of lithology and mineralogy which will enable one to note the relative proportions of feldspar, mica, silica, etc., present, and to determine their specific varieties, is vastly more valuable than dozens of chemical analyses. By means of the microscope the distribution of the various component minerals present cannot only be approximately determined, but the manner in which they are cemented or held together, and their state of decomposition, can be detected without much difficulty.

In some rocks the feldspar and micas are in a more or less decomposed state. When the feldspars are found in such a condition, and appear to be approaching kaolinization, the stone becomes practically worthless for many purposes. Similarly, micas containing large amounts of soda and potash may be very objectionable if they predominate in quantity over the other mineral constituents.

Seasoning.—It has been observed since early Roman times that stone quarried in the warm dry summer months and then allowed to be acted upon by the sun and air for an indefinite length of time becomes somewhat harder. This is due to what is known as the "quarry-water" or "sap" drying out and leaving the stone in a less saturated condition than when it existed in the rock mass. It frequently happens that stones of very good quality are entirely ruined by hard freezing immediately after being taken from the quarry, such being notably the case with some marbles and limestones.* If they are quarried in the warm weather and allowed to become thoroughly dry, the danger is avoided.

This phenomenon is easily accounted for by the supposition that the quarry water carries in solution in some cases carbonate of lime and silica, which is deposited in the cavities of the rock as evaporation proceeds, thus furnishing additional cementing material and rendering the rock more compact.

* Tenth Census of the U. S., Vol. X, Report of the Quarry Industry, p. 27.

"This will also account for the remarkable hardening of some stones after being quarried sometime." "When first quarried they are so soft as to be easily sawed and worked into any desirable shape, but after the evaporation of their quarry water, they become hard and very durable."*

The following bibliographical appendix may be found useful to anyone wishing to pursue the subject further.

BIBLIOGRAPHY.

W. C. Unwin.—"The Testing of Materials of Construction." (London, 1888.)

Tests of Metals, Etc., Ordnance Department, Washington, D. C.—Tests made at Watertown Arsenal.—1881, Vol. I, p. 251; 1883, p. 221; 1887, p. 969; 1890, p. 1099; 1891, p. 723; 1892, p. 607.

Bauschinger.—Mitth. aus dem Mech. Tech. Laboratorium, München, 1884.

I. O. Baker.—"A Treatise on Masonry Construction." (New York, 1889.)

H. Rosenbusch.—"Microscopical Physiography of the Rock-Making Minerals." (New York, 1888.)

Q. A. Gillmore.—"Notes on the Compressive Resistance of Freestone, etc." (New York, 1888.)

Rudolph Gottgetreu.—"Baumaterialien." (Berlin, 1880.)

Tenth United States Census, 1880.—"Building Stones and Quarry Industry."

Q. A. Gillmore.—"Report on the Building Stones of the United States." (Appendix 11 of Annual Report of the Chief of Engineers, U. S. A., 1875.)

History of the St. Louis Bridge, Chapter 25.

Fifth Annual Report of the Geological Survey of Minnesota, p. 47.

G. P. Merrill.—"Stones for Building and Decoration." (New York, 1891.)

Proceedings of the Institution of Civil Engineers.—Vol. I, 231, 234 Vol. X, 241; Vol. XXV, 76, 101, 106; Vol. XLV, 294, 295; Vol. CVII, 341.

Engineering (London), January 18th, 1867, p. 51; September 16th, 1870, p. 211; May 29th, 1885, p. 612.

Encyclopædia Britannica, Vol. IV, p. 469.

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* Tenth Census of the U. S., Vol. X, Report of the Quarry Industry, p. 27.

Journal of the Franklin Institute.—XIV, 58; XIX, 92; XXII, 213; XXIV, 153-200; XL, 214; LVII, 35; LIX, 136; LXV, 168; LXX, 56-373; LXXII, 57; LXXIII, 82-304; LXXV, 13; LXXIX, 397; LXXXVIII, 175; XCVI, 334.

Transactions American Society of Civil Engineers.—Vol. II, 145-151, 167-169, 187-192; Vol. XV, 527, 647-716, 718; Vol. XIX, 152-153.

J. C. Smock.—"Building Stone in New York." Bulletin of the New York State Museum. Vol. 2, No. 10. (Albany, 1890.)

Note.—The literature upon this subject appears to be very scanty, and for that reason some references have been given which bear upon it but indirectly. The list is by no means complete, since there are a number of German publications to which the writer has been unable to obtain access.

DISCUSSION.

A Member.—Have you ever tried the interposition of lead plates?

F. Linwood Garrison, Assoc. M. Am. Soc. C. E.—I have never tried lead plates for the reason that all the testimony I have seen is to the effect that they were very objectionable; they produce transverse strains; the lead flows and thus has a tendency to split the rock. I have used plaster of paris in some instances.

J. F. O'Rourke, M. Am. Soc. C. E.—Do you say the results of the tests of building stone applies as well to artificial stone?

Mr. Garrison.—No, just natural stone.

Mr. O'Rourke.—Would it not be true in regard to specimens for crushing—concrete and cement?

Mr. Garrison.—I cannot answer that question very well. I wrote this paper rather hastily, with a view of bringing out a discussion. My idea was that if we could get the consensus of opinion as to the best method of testing building stone, we could arrive at a better general system of tests. In my opinion it is very essential with all natural stones first to determine what kind of stone it is, of what it is composed, and to understand the mutual of relations of the component elements.

Mr. O'Rourke.—I mean in determining the strength or resistance to pressure.

Mr. Garrison.—I have no doubt the same methods would apply; only a microscopical test would not be so essential, or, in fact, at all necessary. I see no reason why there should not be in general the same tests used.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
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723.

(Vol. XXXII.—August, 1894.)

FRICTION ROLLERS.

By C. L. CRANDALL, M. Am. Soc. C. E., and A. MARSTON, Assoc. M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

PART I.

By C. L. CRANDALL, M. Am. Soc. C. E.

In 1886, the College of Civil Engineering, Cornell University, had a set of plates and rollers made for experimental purposes. The plates were about 1½ ins. thick and 5 ins. wide, and the rollers were 1, 2, 3 and 4 ins. in diameter, all 1½ ins. long, except the first, which were 1 in. long; there being a full set of plates and rollers in cast iron, in steel and in wrought iron.

Mr. C. B. Wing, now Professor of Structural Engineering, Leland Stanford University, undertook the determination of rolling friction for his graduation thesis. Three horizontal plates were put into the testing machine and separated by two parallel rollers, one above and the other below the middle plate; a third roller was placed under the middle plate, to steady it, although receiving but little load.

The force required to produce sensible motion of the middle plate was measured with a spring balance for different loads on the testing machine, and one-half of this force divided by the load was taken for the friction of rest per unit load. The rollers and plates were taken as they came from the tools of the lathe and planer without polishing or filing.

For the 1-in. rollers six different loads were applied, ranging from 350 to 900 lbs., and two determinations were made for each load for each combination of materials, except for the cast-iron rollers, for which only one determination was made for each load. The friction per unit load does not appear to vary with the load, although the individual results vary considerably.

For the 2-in. rollers 12 different loads were applied, ranging from 600 to 2 300 lbs. per lineal inch of roller, with two determinations for each case and apparently no variation with load.

For the 3-in. rollers 12 different loads were applied, ranging from 760 to 2 350 lbs. per lineal inch, with two determinations for each case and a slight tendency for the friction per unit load to increase with the heaviest loads.

For the 4-in. rollers 12 different loads were applied, ranging from 830 to 2 500 lbs. per lineal inch, with two determinations for each case, and with apparently no variation with load.

The unit friction is affected somewhat by the plate, it being 13% greater for the wrought iron and 13% less for the steel than for the cast iron.

The friction is so much affected by the rollers that the values will be given separately for the cast iron, wrought iron and steel.

The usual formula is—

$$P = \frac{b}{r} G \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where P = resistance applied at the center of the roller or wheel; r = radius; G = weight; b = the "coefficient of friction" = the distance the point of support is moved forward by the yielding of the material.

According to the extensive experiments of Morin upon the resistance of wagons upon roads, b is independent of r; according to those of Dupuit, and the more recent ones of Poirée and Sauvage, by means of railroad cars, b varies as $\sqrt{r}$; in the one case P varies as $\frac{1}{r}$, and in the other as in $\frac{1}{\sqrt{r}}$.

The exponent of r being thus uncertain, the formula was put in the form—

Friction per unit load $\frac{P}{G}$, or $F = \frac{b}{r^a}$, or

$$\text{Log. } F = \log. b - a \log. r \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The experiments give the following values for F:

r	F		
	Cast rollers.	Wrought rollers.	Steel rollers.
0.5″	.0082	.0138	.0075
1	45	82	47
1.5	32	63	45
2	31	69	....

These values substituted in (2) will give four observation equations for each material from which to determine the most probable values of a and b. The ordinary method of least squares gives—

$a = 0.75$; $b = .0079$ for cast rollers; $a = 0.55$; $b = .0130$ for wrought; $a = 0.55$; $b = .0073$ for steel.

The formula thus becomes—

Friction per unit load $= \frac{.0079}{r^{.75}}$ for cast rollers.

" " " $= \frac{.0130}{r^{.55}}$ for wrought rollers.

" " " $= \frac{.0073}{r^{.55}}$ for steel rollers.

These nearly conform to the $\sqrt{r}$ formula. Changing to that form we have—

$$\left.\begin{array}{ll} \text{Friction per unit load} = \frac{.0063}{\sqrt{r}} & \text{for cast rollers;} \\ \text{" \quad " \quad "} = \frac{.0120}{\sqrt{r}} & \text{for wrought rollers;} \\ \text{" \quad " \quad "} = \frac{.0073}{\sqrt{r}} & \text{for steel rollers.} \end{array}\right\} \ldots\ldots\ldots\ldots (3)$$

For wrought-iron plates these values should be increased about 13%, and for steel plates decreased by the same percentage.

If these formulas could be extended to the 20-in. cast wheel, rolling upon a cast track, experimented upon by Weisbach and Rittinger (Weisbach's "Mechanics," Vol. I, page 354), they would give the friction

per unit load .0020 instead of .0018, as found by the former, and .0019, as found by the latter. If extended to the 39.4-in. railroad wheels of Pambour (assumed to be wrought iron on wrought-iron rails), they would give the friction per unit load .0027, instead of the .0100 to .0110 actually found by him. The formulas (3) thus give too large a result in the first, and too small a one in the second case, when extended to radii very much greater than those experimented upon, which would not suggest a change in the exponent of r if it is to remain the same for cast and wrought iron.

The next academic year, 1886–87, Mr. Wing, as Fellow in the College, and the writer undertook a series of wearing tests upon these rollers and plates in order to determine the life of rollers for different loads and materials. They were placed in the testing machine with one roller between the upper and middle plates, and two between the middle and lower, their axes all parallel; the full load on the upper roller was thus divided between the two lower ones. The center plate was driven back and forth about ¾ in., rotating the rollers, by means of a small water wheel acting through a connecting rod upon a rod working in guides and attached to the plate by a flexible joint. The number of turns of the crank was registered by an attached odometer. The scale beam was kept balanced at a constant load during the experiment. Motion was continued until the surfaces were injured by wear, but it was found impossible to reach the same degree of wear with all, first on account of the difficulty of examining the surface until the experiment was stopped and the rollers removed, and second, on account of the long time required to produce wear with the lighter loads.

The wearing effect was towards a gradual rusting of the surface, which changed to a blackening, accompanied with black dust of worn-out material as the wear increased; finally, pitting of the surface took place, with a flow of metal at the ends of the rollers and around the edge of the contact portion of the plate. The results are given in the table on the opposite page.

The elastic limit in compression of a short steel rod about 1 in. in area, cut from the rod which furnished the smaller rollers, was found to be 46 000 lbs., and the modulus of elasticity 31 500 000 lbs. The cast iron gave an elastic limit in a short length of 41 000 lbs., an ultimate of 100 000, and a modulus of elasticity of 14 400 000 lbs., all in compression.

Wear of Rollers.

Date.	Odometer revolutions.	Load per lineal inch of roller.	Roller.	Plate.	Condition of Worn Surface. Roller.	Condition of Worn Surface. Plate.
1886. Sept. 16th to Oct. 18th.	299 168	1 510	Wrought iron..	Cast iron	Pitted considerably	Pitted slightly.
		910	2" diameter	1.47" thick.....	Blackened.....	Blackened.
		600	1.5" long.....	"	Slightly blackened	Slightly blackened.
Nov. 1st to Dec. 4th.	233 174	1 890	Wrought iron..	Cast iron.....	Pitted badly, flow of metal at ends.....	Pitted considerably.
		1 240	3" diameter	"	Beginning to pit	Beginning to pit.
		650	1.5" long.....	.....	Blackened.....	Blackened.
Dec. 8th to Jan. 6th.	423 292	2 270	Wrought iron..	Cast iron.....	Pitted slightly	Pitted slightly.
		1 400	4" diameter	"	Blackened, beginning to pit.....	Blackened, beginning to pit.
		670	1.5" long.....	.....	Blackened	Blackened.
1887. Jan. 8th to Feb. 21st	806 483	2 270	Cast iron	Cast iron.....	Blackened	Blackened.
		1 500	4" diameter....	"	Rusted, part blackened	Blackened.
		770	1.5" long.....	.....	Rusted.....	Rusted, part blackened.
Mar. 2d to Mar. 29th	631 642	4 530	Cast iron.....	.....	Blackened, beginning to pit.....	Blackened, beginning to pit.
		2 330	4" diameter....	Cast iron.....	Blackened, beginning to pit at one end...	Blackened, beginning to pit at end.
		2 200	1.5" long.....	"	Blackened.....	Blackened.
April 2d to April 9th	361 154	3 940	Cast iron	"	Blackened, beginning to pit.	
		1 970	3" diameter....	"	Blackened and rusted.	
		1 970	1.5" long.....	.....	Rusted.	
Apr. 26th to May 7th.	277 165	3 260	Cast iron.....	Cast iron.....	Pitting begun.....	Plates show more wear than rollers.
		1 960	2" diameter....	"	Blackened, beginning to pit.	Plates show more wear than rollers.
		1 300	1.5" long	.....	Rusted.	
Oct. 21st to Nov. 2d.	242 033	3 260	Steel	Cast iron.....	Top blackened; bottom deeply pitted; flow of metal at one end.	
		2 290	2" diameter....	1.41" thick.....	Blackened, beginning to pit.	
		970	1.5" long	5" wide	Blackened in streaks.	
Nov. 7th to Nov. 12th	122 755	2 130	Steel	Wrought iron..	Deeply pitted; flow of metal at ends.....	Deeply pitted.
		1 520	2" diameter....	1.47" thick.....	Blackened, beginning to pit.....	Blackened, beginning to pit.
		610	1.5" long.....	.....	Rusted.....	Rusted and blackened.
Nov. 15th to Dec. 1st.	354 145	2 130	Cast iron.....	Wrought iron..	Slightly pitted	Slightly pitted.
		1 650	2" diameter....	" ..	Blackened, beginning to pit.....	Blackened, beginning to pit.
		480	1.5 long.....	.....	Rusted.....	Rusted.
Dec. 1st to Dec. 9th.	138 580	2 130	Wrought iron..	Wrought iron..	Slightly pitted	Pitted.
		1 160	2" diameter	" ..	Pitted.....	Pitted.
		970	1.5" long.....	.....	Blackened and rusted.....	Blackened and rusted.
Dec. 9th to Dec. 30th	468 088	2 130	Steel	Steel.....	Blackened.....	Blackened, one end polished.
		1 090	2" diameter....	.....	Rusted.....	Rusted.
		1 040	1.5" long.....	.....	Rusted and blackened.....	Rusted and blackened.

It is not felt that these experiments will give more than a hint at the effect of diameter, load and material upon the wear of rollers; but they may serve as a nucleus about which to collect the results of others, both from the field and laboratory.

In order to determine what a certain number of revolutions of the odometer means with reference to the life of a bridge roller, observations were taken upon a Lehigh Valley Railroad bridge of some 100-ft. span over Fall Creek at Ithaca, during the passage of slow-moving freight trains, and upon a Delaware, Lackawanna and Western Railroad bridge over the Chemung, near Waverly, during the passage of faster freight trains. Both bridges had been recently erected. The first was a through bridge upon masonry abutments. The roller end moved out when the train entered, and back when it passed off, with no vibration or other motion for the ordinary short trains of that branch of the road. The second was a deck double-track bridge of some 160-ft. span, with the fixed end upon a masonry abutment, and the roller end upon a masonry pier, 7.5 ft. wide at the top and some 25 ft. high above the stream. The roller end vibrated considerably, but most of the vibration was transmitted to the pier without moving the rollers. One short train of an engine and two cars gave a motion of the rollers out and back, with some eight vibrations of about $\frac{1}{30}$ in. each. Three long freight trains gave three motions out and back each, with no vibration of sufficient amplitude to be recorded on the self-registering apparatus.

For medium spans on heavy traffic roads, it is believed that 10 motions per train is not above the actual. This would correspond to an odometer reading of 73 000 per year for a road of 10 daily trains each way, requiring but a very few years to reach the numbers in the above table, without allowance for the dirt and rust of the actual bridge rollers.

During the next academic year, 1887–88, experiments were made to determine the effect of load and diameter upon the area of contact between the roller and plate, and also to find the elastic limit, in order to test the Grashof roller formula. The same rollers and plates were used as in the experiments already described. The results have been discussed by Professor Marston in connection with this paper, and need not be repeated here.

The Grashof formula not being satisfactory theoretically, and not

giving results agreeing with experiment, it was felt that valuable data in regard to the actual distribution of stress in the roller could be obtained by examining a glass roller under stress by means of polarized light. Accordingly, the college purchased a 1-in. and a 2-in. roller of optical glass of Brashear. No one was found to take up this portion of the work until Professor Marston came to the college for graduate work during his own vacation in December, 1892. A cube of optical glass was added, and suitable apparatus placed at his disposal for carrying on the work, which was begun at Cornell and completed at Ames, Ia. He also extended and supplemented the metal roller contact experiments, as more fully described in the able paper given as Part II.

PART II.

By A. Marston, Assoc. M. Am. Soc. C. E.

The investigation described below was begun in the winter of 1892–93 at the suggestion of Professor Charles L. Crandall, of the College of Civil Engineering of Cornell University, whom the writer had assisted while a student at the University in 1887 and 1888, in making a series of tests of bridge rollers. The material for the experiments with polarized light described below was supplied by Cornell University, at which the writer was spending part of a vacation when the work was begun. The investigation has been continued at such times as he could spare from his regular duties. The writer desires to acknowledge here his indebtedness to Professor W. S. Franklin, of the Department of Physics, Iowa State Agricultural College, for assistance in developing the method of studying strains by polarized light.

The fact that stressed glass bodies exhibit striking optical effects when viewed by polarized light has long been known, and the exhibition of these effects is one of the standard experiments of the physical lecture-room. Previous attempts, also, have been made to utilize these effects in the study of stresses. Wertheim long since invented a device by which he used the colors of polarization in determining the intensity of stress uniformly applied,* and Mr. Louis Nickerson, M. Am. Soc. C. E. (deceased), attempted to determine the position of the neutral axis in beams by experiments with polarized light.† Mr. Nickerson's interpretation of his results, how-

* See *Comptes Rendus* 32, page 289 (1851), and *Phil. Magazine* (4) 8, page 241 (1854).

† See *Transactions*, Vol. III, page 31.

ever, was based upon a misconception of their true meaning. Since writing this paper, the attention of the writer has been called to the fact that Professor C. A. Carns Wilson published an article in the *Philosophical Magazine* for December, 1891, entitled "The Influence of Surface Loading on the Flexure of Beams," which gives the lines of stress as found experimentally by polarized light. The method used by the writer in this work was described in the *Physical Review* of Cornell University for September–October, 1893.

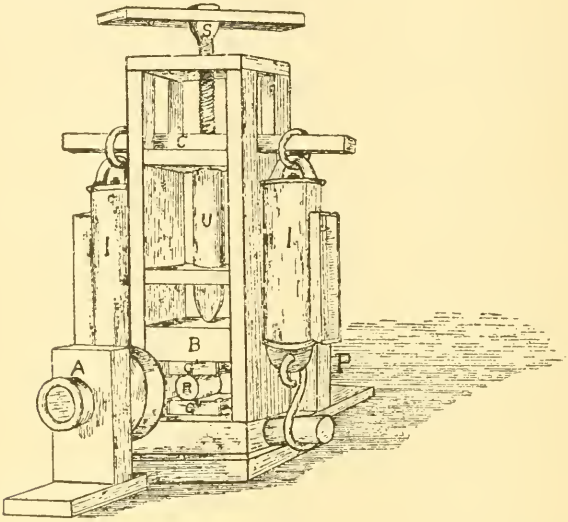
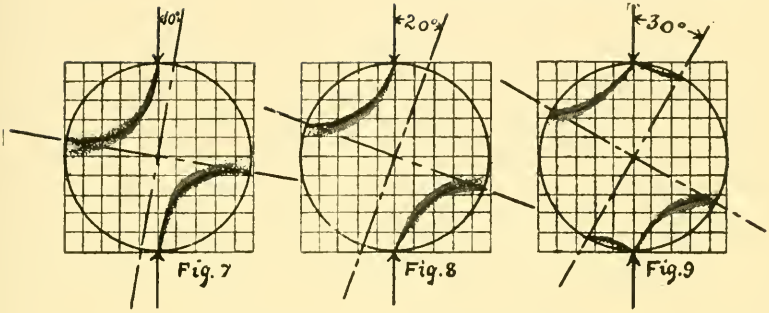


Figure 1.

The use of this method in the study of the distribution of the stresses in a bridge roller will be better understood after the apparatus used in the experiments has been described. This apparatus is shown in Fig. 1. By means of the screw *S* working in the steel cross-piece *C*, pressure was applied to the upright pin *U* and thence to the loose block *B*, and glass plate *G'*. Between this plate and another *G''* the roller to be examined was placed. *U* had a ball-bearing on *B*. The amount of the pressure was measured by the sum of the readings of the two ice scales *I*, *I*, plus the weight of *B*, *U*, *C*, *S*, and *I*, *I*.

The analyzer *A* was a Nicol's prism set in a brass tube in the usual manner, and for these experiments mounted in an upright block of wood as shown in the figure. By means of a graduated paper strip



LINES OF STRESS BY POLARIZED LIGHT.

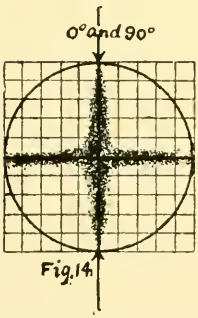
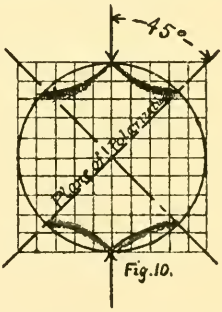
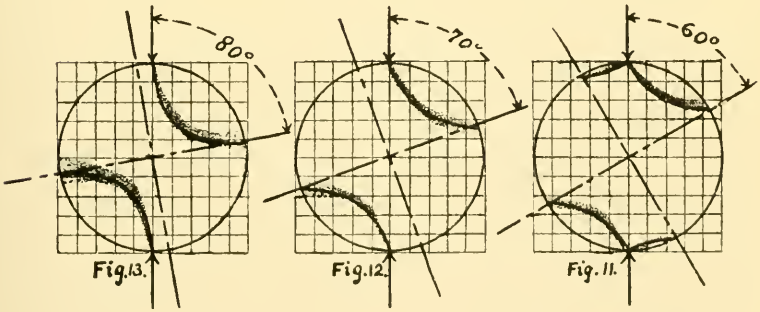


PLATE I.



Diameter of Roller, 1 in; Length, 1 in; load, 400 lbs.



pasted on the brass tube, the plane of polarization could be set (within a degree or two) at any desired angle with the vertical. The polarizer *P* (mostly hid from view by the other parts of the apparatus in the figure) was a similar Nicol's prism, similarly mounted.

The two rollers studied by this apparatus in these experiments were of optical glass, 1 in. long, and respectively 1 in. and 1.98 ins. in diameter. The ends were polished, and the cylindrical surfaces ground true. The rollers were made by Brashear, of Pittsburgh, Pa. They bore above and below against pieces of plate glass $1\frac{1}{2}$ x 1 x $\frac{1}{3}$ ins.

When the planes of polarization of the polarizer and analyzer were set at right angles to each other (prisms crossed), and the observer looked through the analyzer at the end of the roller, the following phenomena were observed : With no load on the roller the whole of its face was dark ; with a load (of 200 lbs., say) on the roller, the light was restored over most of the face of the roller, but there still remained dark bands, which moved when the prisms were rotated. There were also color bands which varied as described below.

When the planes of polarization of the polarizer and analyzer were set parallel (prisms parallel), the roller was clear in the unstressed condition, and only color effects were observed when the roller was loaded. The colors were in bands of yellow, red and blue (see Plates XVI and XVII) and varied in position as the load changed, and in brightness (though not in position) as the prisms were rotated.

In the article in the *Physical Review*, already referred to, it is shown that the dark bands seen when the prisms are crossed give the loci of the points where the lines of stress are parallel or perpendicular to the plane of polarization of the polarizer *P*, while the colors observed give the differences between the principal stresses, at the points where they are observed, according to the table on page 108.

Thus polarized light affords a means, first, to determine the lines of stress throughout the roller, and second, to check the intensities of the principal stresses as given by the formulas of any solution of the equations of elasticity for this case. In order to obtain these results a systematic series of observations of the dark bands and color bands was made for different loads for each of the rollers above described. To sketch the bands accurately, the face of the roller under observation was divided into $\frac{1}{10}$-in. squares by fine threads stretched in a brass frame, placed against the roller. The sketches were made on figures similarly divided, as shown in Plates XIV to XVII.

TABLE No. 1.

DIFFERENCES BETWEEN PRINCIPAL STRESSES CORRESPONDING TO THE COLORS OF POLARIZATION IN ROLLERS 1 IN. LONG.

Color.	Difference.	Color.	Difference.
Clear.....	100 lbs. per square inch.	Third red.....	2 550 lbs. per square inch.
Cloudy.....	200 " "	Green.....	3 000 " "
Faint yellow...	300 " "	Fourth red.....	3 650 " "
Bright yellow..	400 " "	Green.....	4 050 " "
First red.....	525 " "	Fifth red.....	4 750 " "
Blue.....	600 to 900 " "	Green.....	5 250 " "
Yellow.....	1 200 " "	Sixth red.....	5 900 " "
Second red.....	1 550 " "	Green.....	6 450 " "
Greenish blue..	1 800 " "	Seventh red....	7 050 " "
Greenish yellow	2 100 " "		

Plates XIV and XV show the dark bands observed under the loads stated on the plates, with the plane of polarization of the polarizer set at the angles with the vertical indicated on the figures, the prisms being crossed. For the sake of clearness, the color effects are omitted from these plates. Similar observations were made for loads of 100 lbs., 200 lbs. and 300 lbs., the results being the same as in the figures given.

Plates XVI and XVII show the color bands observed with the prisms parallel, under the loads stated on the plates. Each of the figures in these plates was made by combining the results of a series of observations with the plane of polarization of the polarizer set at different angles with the vertical, for in no one position of the polarizer could the color bands be seen throughout their whole extent.

A study of the results given in Plates XIV and XV, and of the observations made for the other loads (but not given here) showed that the position of the dark bands did not vary (except at the points of contact of the plates) for different loads. This showed that the lines of stress were the same for different loads. To determine the exact nature of the lines of stress, the case of the 1-in. roller sustaining a load of 400 lbs. may be taken. The dark bands for this case are given in Figs. 7 to 14, Plate XIV. The middle lines of these bands are grouped on one figure in Fig. 2, and show the angles of inclination of the lines of stress to the vertical at different points in the roller. Starting at any point on the horizontal diameter, as A, the line of stress through this point may be approximately drawn by first drawing a short vertical arc, then one inclined 5° to the vertical and extending nearly to

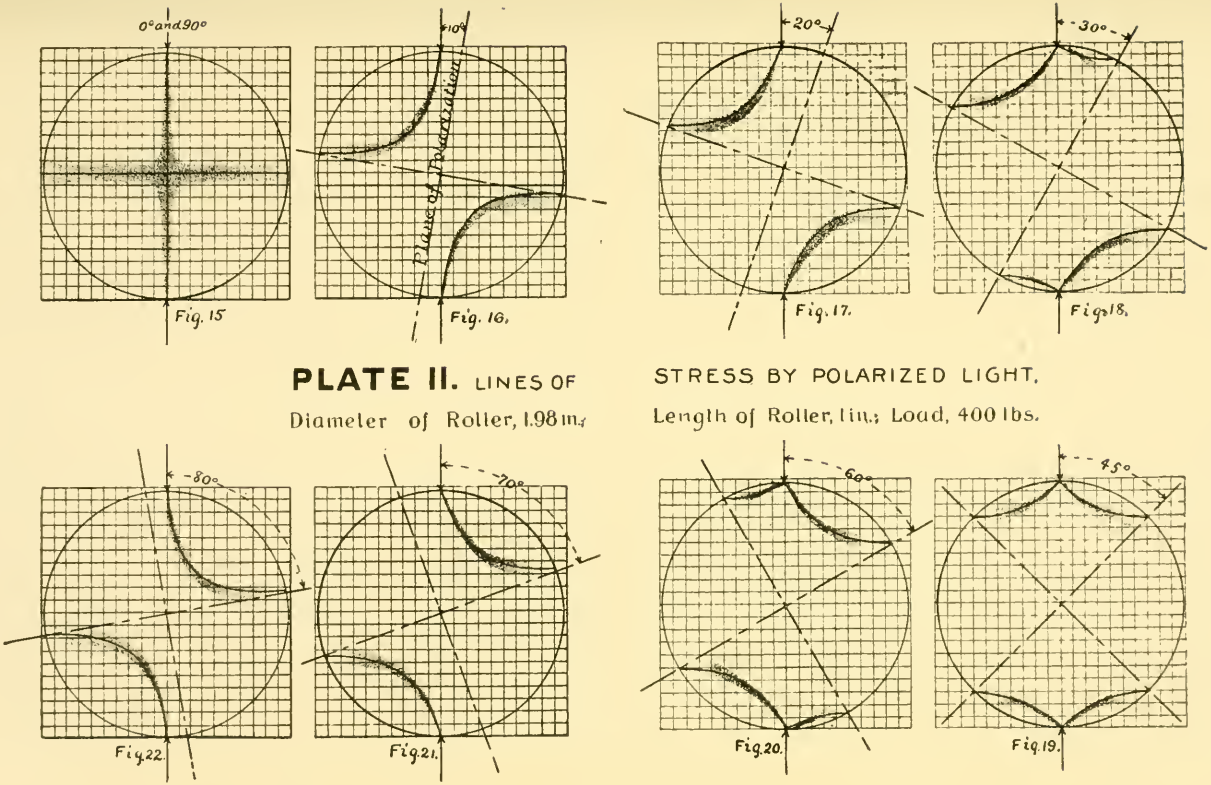


PLATE II. LINES OF STRESS BY POLARIZED LIGHT.

Diameter of Roller, 1.98 in.; Length of Roller, 1 in.; Load, 400 lbs.

the 10° line, then one inclined 10° to the vertical running past the 10° line, and so on. By repeating this process for different points, the lines of stress were found as shown in Fig. 2.

On trying these lines of stress with a pair of dividers, they seemed to be arcs of circles. To decide whether such be the case, the positions for the middle lines of the dark bands in Plates XIV and XV may be cal-

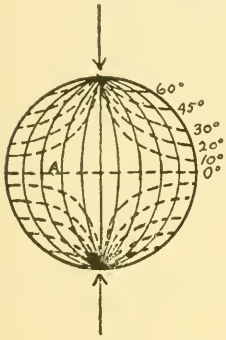


Fig. 2.

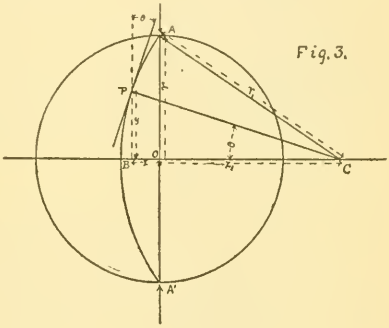


Fig. 3.

culated on this supposition and the results compared with the actual positions. The equation of the dark band corresponding to any angle Θ of the plane of polarization with the vertical may be found as follows: In Fig. 3 let P be any point of the dark band. The line of stress through this point makes an angle Θ with the vertical at P. Let the line of stress be an arc of a circle passing through A and A', and let C be its center. Then from triangle OAC—

$$r^2_1 = x^2_1 + r^2,$$

and from triangle PBC,

$$r^2_1 = y^2 + x^2 - 2xx_1 + x_1^2.$$

Hence, $r^2 = x^2 + y^2 - 2xx_1.$

But, $x_1 = y \cot. \Theta + x,$

hence, $r^2 = y^2 - 2xy \cot. \Theta - x^2,$

whence, $y = x \cot. \Theta \pm \sqrt{r^2 + x^2 \csc^2 \Theta} \ldots\ldots (1)$

which is the required equation.

From this equation the lines which should coincide with the middles of the dark bands are platted on the figures in Plates XIV and XV. Inspection of the results shows that the lines practically coincide with the actual dark bands observed. Hence it may be considered as proven that the lines of stress in a bridge roller are, at least ap-

proximately, arcs of circles. A mathematical demonstration of this fact will be given further along, but it was first ascertained in the manner given.

The color effects shown in Plates XVI and XVII are very striking. If the stresses in the roller were simple stresses, these colors would give the approximate numerical value of the intensity of the stress at each point of the roller. The stresses, however, are in fact compound stresses, and what the colors do give is the differences between the principal stresses. Hence they will serve to check any theoretical solution of the problem of finding the stresses, but do not give data for forming the theory. To make use of these colors it was necessary, therefore, to attempt the solution of the general equations of elasticity for the case of the roller loaded as in the experiments, or as when under the end of a bridge.

In the solution of this problem the standard notation for stresses, displacements and constants of elasticity will be adopted, as follows:

At any point (x, y, z) in an elastic solid—

Let $u =$ the displacement parallel to the axis of X;

$v =$ " " " " " Y;

$w =$ " " " " " Z;

$P =$ normal stress on the plane perpendicular to the axis X;

$Q =$ " " " " Y;

$R =$ " " " " Z;

$S =$ the shear tending to produce rotation about the axis X;

$T =$ " " " " Y;

$U =$ " " " " Z,

and let the subscripts p and r denote the stresses and displacements in the bearing plate and roller respectively. P, Q and R are $+$ for tensions. S, T and U are $+$ for shears tending to make the upper right-hand corner of a rectangular element acute, when *up* and *to the right* are the $+$ directions of the axes of co-ordinates.

Let $\mu =$ modulus of rigidity, $= \dfrac{2(1+\sigma)}{E}$

$$\lambda = \frac{E\sigma}{(1+\sigma)(1-2\sigma)}.$$

$E =$ Young's modulus of elasticity.

$\sigma =$ ratio of lateral contraction to longitudinal expansion.

$W =$ load per unit of length of roller.

$r =$ radius, $d =$ diameter, and $l =$ length, of roller.

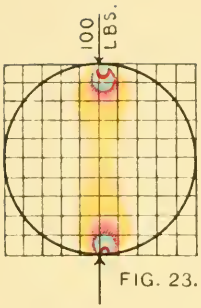


FIG. 23.

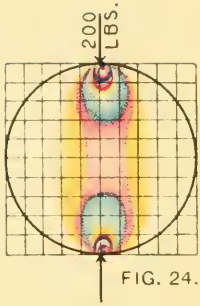


FIG. 24.

PLATE III

INTENSITY OF STRESS BY POLARIZED LIGHT.

1" ROLLER, 1" LONG.

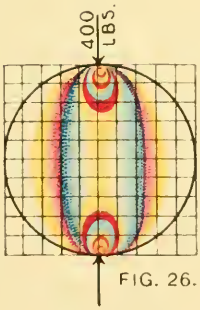


FIG. 26.

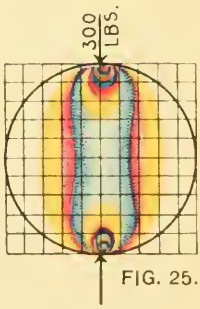


FIG. 25.

Also let $\triangle =$ the cubical dilatation, $= \frac{\delta u}{\delta x} + \frac{\delta v}{\delta y} + \frac{\delta w}{\delta z}$, (where the character δ denotes partial differentiation) and let ∇^2 denote the operator, $\frac{\delta^2}{\delta x^2} + \frac{\delta^2}{\delta y^2} + \frac{\delta^2}{\delta z^2}$.

Then, from Love's "Theory of Elasticity," page 76, the stresses are given in terms of the displacements by the equations—

$$\left.\begin{array}{l} P = \lambda\triangle + 2\mu \frac{\delta u}{\delta x}, \text{ with similar equations for } Q \text{ and } R, \\ \text{and } S = \mu\left(\frac{\delta w}{\delta y} + \frac{\delta v}{\delta z}\right) \text{ with similar equations for } T \text{ and } U; \end{array}\right\} \ldots\ldots(2)$$

And the fundamental equations of elastic equilibrium are

$$\left.\begin{array}{r} (\lambda + \mu)\frac{\delta \triangle}{\delta x} + \mu \nabla^2 u = 0, \\ (\lambda + \mu)\frac{\delta \triangle}{\delta y} + \mu \nabla^2 v = 0, \\ \text{and } (\lambda + \mu)\frac{\delta \triangle}{\delta z} + \mu \nabla^2 w = 0. \end{array}\right\} \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The general problem of elasticity for any particular solid is to find systems of displacements and stresses which satisfy equations (2) and (3), and which at each point of the boundary of the solid give stresses equal to the components of the external load at that point.

The general problem of elasticity has been solved by Boussinesq, and also by Cerruti, for the case of a force parallel to the axis Y, acting at the origin of co-ordinates, on an infinite elastic solid, bounded by the plane $y = 0$. If the amount of the force be $W\,dz$, the resulting displacements are (see Love's "Theory of Elasticity," page 270)—

$$\left.\begin{array}{l} u' = -\frac{W\,dz}{4\pi(\lambda+\mu)}\frac{x}{h_o(y+h_o)} + \frac{W\,dz}{4\pi\mu}\frac{xy}{h_o^3}, \\ v' = +\frac{W\,dz(\lambda+2\mu)}{4\pi\mu(\lambda+\mu)}\frac{1}{h_o} + \frac{W\,dz}{4\pi\mu}\frac{y^2}{h_o^3}, \\ w' = -\frac{W\,dz}{4\pi(\lambda+\mu)}\frac{z}{h_o(y+h_o)} + \frac{W\,dz}{4\pi\mu}\frac{yz}{h_o^3}, \end{array}\right\} \ldots\ldots\ldots(4)$$

from which the stresses P, Q, etc., can be computed by (2) above.

In equation (4) $h_o =$ the distance from the point (x, y, z) to the origin of co-ordinates. Since the force $W\,dz$ must actually be applied over a small area instead of at a point, the solution holds true only for points at appreciable distances from the origin.

Now, suppose a load of length l, and of uniform intensity W per

unit of length, to press upon the infinite solid along the axis of Z, as in Fig. 4, giving a case similar to that of a bridge roller resting on a pier of the same material as the bearing plate, and let the origin be at the middle of the load (or roller). It is evident that the displacements and stresses at any point (x, y, z') of the solid will be equal to the integrals of (4), and of the corresponding stresses, between the limits

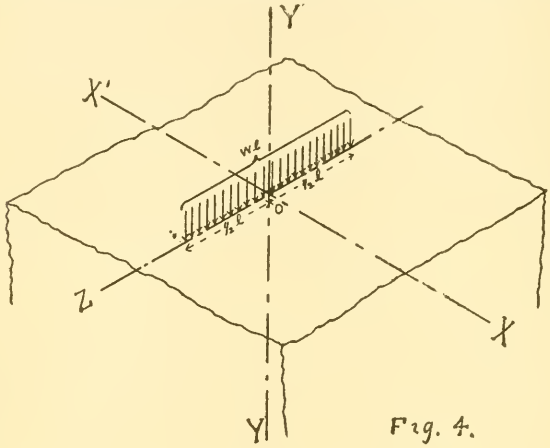


Fig. 4.

of $z' - \frac{1}{2} l$ and $z' + \frac{1}{2} l$. The resulting expressions are very complicated. If, however, the solution be limited to points close to the middle of the roller, and to values of x and y which are small in comparison with l, the formulas are much simplified, and become, after substituting for λ and μ in terms of E and σ,

$$\left.\begin{aligned}
u_p &= -\frac{W(1+\sigma)(1-2\sigma)}{\pi E}\cot.^{-1}\frac{y}{x} + \frac{W(1+\sigma)}{\pi E}\frac{xy}{h^2},\\
v_p &= +\frac{W(1+\sigma)(1-\sigma)}{\pi E}\log.\frac{l^2}{h^2} + \frac{W(1+\sigma)}{\pi E}\frac{y^2}{h^2},\\
w_p &= 0,\\
P_p &= -\frac{2W}{\pi}\frac{x^2 y}{h^4},\\
Q_p &= -\frac{2W}{\pi}\frac{y^3}{h^4},\\
R_p &= -\frac{2W\sigma}{\pi}\frac{y}{h^2},\\
S_p &= 0,\\
T_p &= 0,\\
U_p &= -\frac{2W}{\pi}\frac{xy^2}{h^4},
\end{aligned}\right\}\quad\ldots(5)$$

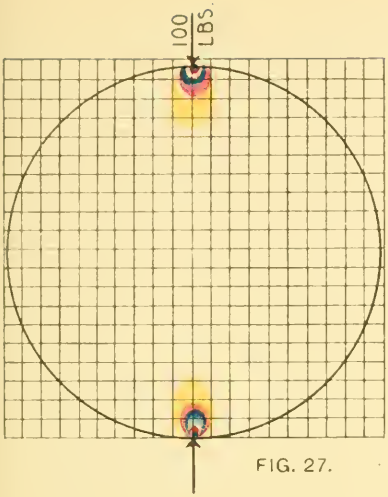


FIG. 27.

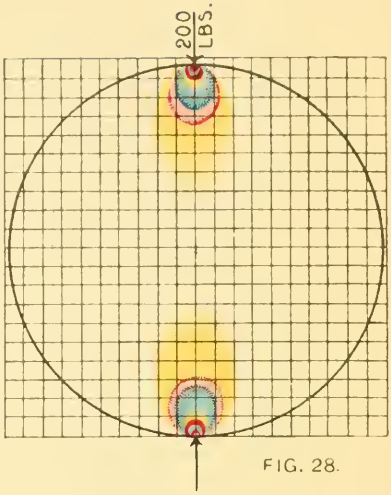


FIG. 28.

PLATE IV

INTENSITY OF STRESS BY POLARIZED LIGHT.

1.98" ROLLER, 1" LONG.

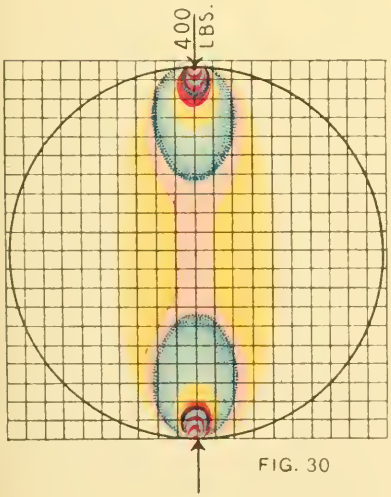


FIG. 30

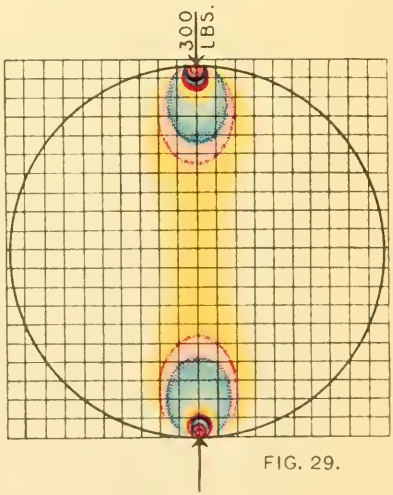


FIG. 29.

where $h =$ the perpendicular distance from the point x, y, z, to the axis of z, and the logarithms are Napierian logarithms. It may readily be verified that the displacements above satisfy the fundamental equations (3), and that the stresses satisfy the boundary conditions.

The solution in (5) applies strictly, as has been said, only to the case where the bearing plate rests on a pier of the same material as itself. Practically, however, it does not seem probable that the nature of the material on which the bearing plate would actually rest will appreciably affect the stresses in it. Again, although the solution is strictly correct only for points in the plate near the middle of the roller, where x and y are small in comparison with l, yet, if the roller extends to the edge of the plate, they may be considered as a section of a roller and plate of infinite length, for which the solution would be true at all points of the plate. The only difference is that the roller and plate in the actual case are free to expand parallel to the axis of the roller, which will modify the value of R_p, but probably not greatly affect the other stresses.

On the whole, therefore, it may be said with some confidence that

$$\left.\begin{aligned} P_p &= -\frac{2W}{\pi}\,\frac{x^2y}{h^4}, \\ Q_p &= -\frac{2W}{\pi}\,\frac{y^3}{h^4}, \\ U_p &= -\frac{2W}{\pi}\,\frac{xy^2}{h^4}, \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

are the stresses in a bearing plate under the end of a bridge due a roller as long as the plate is wide, loaded with a weight W per unit of length.

In (6) the axis of Z is the line of contact between the roller and the plate, and the axis of Y is taken vertical. $h =$ the perpendicular distance from the point (x, y, z) to the axis of Z. The stress on planes perpendicular to the axis of the roller is left out of account, it being assumed that it is normal to the planes. The equations do not hold true for points very close to the line of contact for the reason that there will, in reality, be a surface instead of a line of contact.

It will be seen that equations (6) are very simple in form. They can be still further simplified as follows :

Let N_p' and N_p'' be the principal stresses at any point of the plate, and let Θ_p be the angle which the line of stress at the point makes

with the vertical. Then, from Rankine's "Civil Engineering," pages 169 and 170—

$$\left.\begin{aligned} N_p' &= \frac{Q_p + P_p}{2} + \sqrt{\frac{(Q_p - P_p)^2}{4} + U_p^2}, \\ N_p'' &= \frac{Q_p + P_p}{2} - \sqrt{\frac{(Q_p - P_p)^2}{4} + U_p^2}, \\ \Theta_p &= \tfrac{1}{2} \tan.^{-1} \frac{2\, U_p}{Q_p - P_p} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots (7)$$

From (7) and (6),

$$\left.\begin{aligned} N_p' &= O, \\ N_p'' &= -\frac{2\, W}{\pi} \frac{y}{h^2}, \\ \Theta_p &= \tan.^{-1} \frac{x}{y}, \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots (8)$$

From (8) it is seen at once that the lines of stress in a bearing plate, pressed as for (6) are straight lines perpendicular to the line of contact between roller and plate, and radiating from it, and that the stress is a simple compression, directed towards the line of contact, and of amount—

$$N_p = -\frac{2\, W}{\pi} \frac{\cos.\ \Theta}{h}, \quad \ldots\ldots\ldots\ldots (9)$$

where Θ is the angle which any line of stress makes with the vertical, and h and W are as for (6). The axes of co-ordinates are taken as for (6), and the formula is subject to the same limitations. It will be more nearly correct at the middle of the plate than elsewhere.

(9) is very interesting as showing the law by which a uniform load applied to an elastic solid along a surface line distributes itself into the body of the solid.

To obtain a solution for the stresses in the roller itself, conceive the roller to be inscribed in a plate of thickness $2\,r$ (where r = the radius of the roller), and of width equal to the length of the roller, as in Fig. 5.

It is evident that (5) gives the stresses in such a plate, for, 1st, the load W per unit of length along the upper line of contact of the roller; 2d, to the distribution of stress over the lower face of the plate found by substituting $2\,r$ in the values of Q_p and U_p given in (5); 3d, to a distribution of stress over each side edge of the plate equal to the R_p of (5).

These stresses in the plate may be transformed to axes of co-ordin-

ates through the center of the roller as in Fig. 5, by substituting $r - y$ for y in (5). From this it is evident that the system of stresses—

$$\left.\begin{aligned}
P'' &= -\frac{2\,W}{\pi}\left[\frac{x^2(r-y)}{h_1^4} + \frac{x^2(r+y)}{h_2^4}\right],\\
Q'' &= -\frac{2\,W}{\pi}\left[\frac{(r-y)^3}{h_1^4} + \frac{(r+y)^3}{h_2^4}\right],\\
R'' &= -\frac{2\,W\sigma}{\pi}\left[\frac{(r-y)}{h_1^2} + \frac{(r+y)}{h_2^2}\right],\\
S'' &= 0,\\
T'' &= 0,\\
U'' &= +\frac{2\,W}{\pi}\left[\frac{x\,(r-y)^2}{h_1^4} - \frac{x\,(r+y)^2}{h_2^4}\right]
\end{aligned}\right\}\quad\ldots\ldots\ldots\ldots(10)$$

[where h_1 and h_2 are the respective perpendicular distances from the point (x, y, z) to the upper and lower lines of contact of the roller] gives the stresses in the plate of Fig. 5, due, 1st, to the loads W per unit of length along each line of contact of the roller as in Fig. 5; 2d, to a distribution of stress over each face equal to the Q_p, and U_p of (5) when $2\,r$ is substituted for y; 3d, to the distribution of stress R'' over each side edge of the plate.

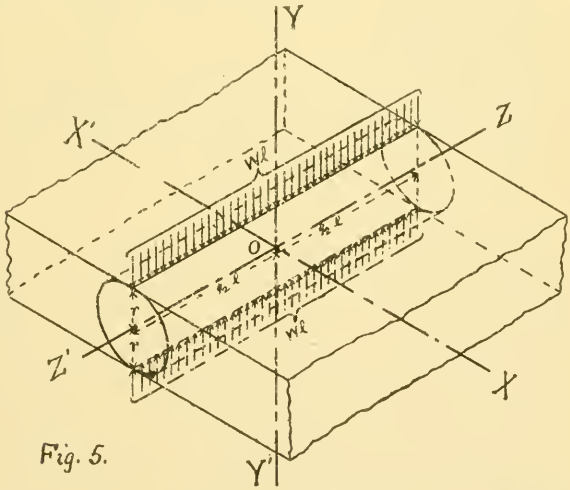


Fig. 5.

Or, they are the stresses in the roller shown in Fig. 5, due, 1st, to the load W per unit of length along each line of contact of the roller; 2d, to the reaction of the plate against the cylindrical surface of the roller; 3d, to the distribution of stress R'' over each end of the roller.

The reaction of the plate against the cylindrical surface may be computed by substituting $x^2 + y^2 = r^2$ in the expressions for P'', Q'' and T'' in (10). The results are $P''_s = -\frac{W}{\pi r}$, $Q''_s = -\frac{W}{\pi r}$, and $T''_s = 0$.

Thus the stresses caused by the reaction of the plate against the roller may be nullified by adding to the P'' and Q'' of (10) the uniform tensile stresses $P''' = \frac{+W}{\pi r}$, and $Q''' = +\frac{W}{\pi r}$.

The double integral of R'' over the end of the roller $= -4\ W\sigma r$. It is well known that any two equal and opposite forces, parallel to the axis, applied symmetrically, one at each end of a cylinder, cause a simple uniform stress at all points in the cylinder except those very close to the ends, equal in amount to the quotient of one of the forces divided by the area of a right section of the cylinder. Hence the stresses due to the distribution of stress R'' over each end of the roller may be nullified by adding to the R'' of (10) the uniform tensile stress $+\frac{4\ W\sigma r}{\pi r^2} = +\frac{4\ W\sigma}{\pi r}$.

Making these corrections to (10), and calculating the corresponding displacements, the complete solution for the stresses and displacements in a roller of radius r, pressed above and below by loads W per unit of length is as follows :

$$\left.\begin{aligned}
u_r &= -\frac{W(1+\sigma)(1-2\sigma)}{\pi E}\left[\cot.^{-1}\frac{(r-y)}{x} + \cot.^{-1}\frac{(r+y)}{x}\right] \\
&\quad + \frac{W(1+\sigma)}{\pi E}\left[\frac{x(r-y)}{h_1^2} + \frac{x(r+y)}{h_2^2}\right] + \frac{W(1-\sigma-4\sigma^2)}{\pi E}\frac{x}{r}, \\
v_r &= +\frac{W(1+\sigma)(1-\sigma)}{\pi E}\log.\frac{h_1^2}{h_2^2} - \frac{W(1+\sigma)}{\pi E} \\
&\quad \left[\frac{(r-y)^2}{h_1^2} - \frac{(r+y)^2}{h_2^2}\right] + \frac{W(1-\sigma-4\sigma^2)}{\pi E}\frac{y}{r}, \\
w_r &= +\frac{2\ W\sigma}{\pi E}\frac{z}{r}, \\
P_r &= -\frac{2\ W}{\pi}\left[\frac{x^2(r-y)}{h_1^4} + \frac{x^2(r+y)}{h_2^4}\right] + \frac{W}{\pi r}, \\
Q_r &= -\frac{2\ W}{\pi}\left[\frac{(r-y)^3}{h_1^4} + \frac{(r+y)^3}{h_2^4}\right] + \frac{W}{\pi r}, \\
R_r &= -\frac{2\ W\sigma}{\pi}\left[\frac{(r-y)}{h_1^2} + \frac{(r+y)}{h_2^2}\right] + \frac{4\ W\sigma}{\pi r}, \\
S_r &= 0, \\
T_r &= 0, \\
U_r &= +\frac{2\ W}{\pi}\left[\frac{x(r-y)^2}{h_1^4} - \frac{x(r+y)^2}{h_2^4}\right].
\end{aligned}\right\} \ldots(11)$$

In (11) the axes of co-ordinates are taken as in Fig. 5, h_1 = the perpendicular distance from the point (x, y, z) to the upper line of contact, and h_2 = the corresponding distance to the lower line of contact. The logarithms are Napierian logarithms. It may readily be verified that (11) satisfies (2), and (3), and the boundary conditions. The solutions do not hold true except at points sensibly distant from the areas of contact for the reason already given in connection with the bearing plate.

TABLE No. 2.

THEORETICAL STRESSES IN A ROLLER 1 IN. IN DIAMETER DUE TO A LOAD W PER LINEAL INCH OF ROLLER.

x	y	P_r	Q_r	U_r	N'_r	N''_r	$N'_r - N''_r$
0.0″	0.0″	+ 0.637 W	− 1.910 W	0	+ 0.637 W	− 1.910 W	2.546 W
0.0″	+ 0.1″	+ 0.637 W	− 2.016 W	0	+ 0.637 W	− 2.016 W	2.653 W
0.0″	+ 0.2″	+ 0.637 W	− 2.395 W	0	+ 0.637 W	− 2.395 W	3.031 W
0.0″	+ 0.3″	+ 0.637 W	− 3.342 W	0	+ 0.637 W	− 3.342 W	3.978 W
0.0″	+ 0.4″	+ 0.637 W	− 6.437 W	0	+ 0.637 W	− 6.437 W	7.073 W
− 0.1″	0.0″	+ 0.542 W	− 1.717 W	0	+ 0.542 W	− 1.717 W	2.260 W
− 0.1″	+ 0.1″	+ 0.521 W	− 1.777 W	− 0.185 W	+ 0.535 W	− 1.792 W	2.327 W
− 0.1″	+ 0.2″	+ 0.428 W	− 1.955 W	− 0.448 W	+ 0.509 W	− 2.037 W	2.546 W
− 0.1″	+ 0.3″	+ 0.115 W	− 2.172 W	− 0.922 W	+ 0.441 W	− 2.497 W	2.938 W
− 0.1″	+ 0.4″	− 0.964 W	− 1.645 W	− 1.515 W	+ 0.248 W	− 2.857 W	3.105 W
− 0.2″	0.0″	+ 0.334 W	− 1.255 W	0	+ 0.334 W	− 1.255 W	1.589 W
− 0.2″	+ 0.1″	+ 0.286 W	− 1.241 W	− 0.223 W	+ 0.319 W	− 1.274 W	1.592 W
− 0.2″	+ 0.2″	+ 0.121 W	− 1.157 W	− 0.456 W	+ 0.267 W	− 1.303 W	1.571 W
− 0.2″	+ 0.3″	− 0.203 W	− 0.864 W	− 0.619 W	+ 0.168 W	− 1.235 W	1.404 W
− 0.2″	+ 0.4″	− 0.414 W	− 0.260 W	− 0.366 W	+ 0.037 W	− 0.711 W	0.749 W
− 0.3″	0.0″	+ 0.141 W	− 0.740 W	0	+ 0.141 W	− 0.740 W	0.881 W
− 0.3″	+ 0.1″	+ 0.100 W	− 0.694 W	− 0.149 W	+ 0.127 W	− 0.721 W	0.849 W
− 0.3″	+ 0.2″	− 0.013 W	− 0.543 W	− 0.252 W	+ 0.088 W	− 0.644 W	0.732 W
− 0.3″	+ 0.3″	− 0.127 W	− 0.276 W	− 0.223 W	+ 0.032 W	− 0.436 W	0.469 W
− 0.3″	+ 0.4″	0	0	0	0	0	0

The stresses given in (11) may now be checked by comparison with the polarized light experiments. Let N'_r be the principal stress at any point at right angles to the line of stress passing through the point, and let N''_r be the principal stress in the direction of the line of stress. When P_r, Q_r and U_r are calculated by (11), N'_r and N''_r may be calculated by equations similar to (7).

The results in the 1-in. roller are given in Table No. 2.

For the 1.98-in. roller the results are given in Table No. 3.

By comparing the values of $N'_r - N''_r$ with Table No. 1, it may readily be ascertained what the colors should be at the different points of the figures in Plates XVI and XVII, to check with equa-

tions (11). On the original drawings, in the writer's possession, the theoretical colors are everywhere the same as the actual.

TABLE No. 3.

THEORETICAL STRESSES IN A ROLLER 1.98 INS. IN DIAMETER DUE TO A LOAD W PER LINEAL INCH OF ROLLER.

x	y	P_r	Q_r	U_r	N'_r	N''_r	$N'_r - N''_r$
0.0″	0 0″	+ 0.321 W	− 0 964 W	0	+ 0.321 W	− 0.964 W	1.286 W
0 0″	+ 0.2″	+ 0.321 W	− 1.019 W	0	+ 0 321 W	− 1.019 W	1.341 W
0.0″	+ 0.4″	+ 0.321 W	− 1.215 W	0	+ 0.321 W	− 1.215 W	1.537 W
0.0″	+ 0.6″	+ 0.321 W	− 1.711 W	0	+ 0 321 W	− 1.711 W	2.033 W
0.0″	+ 0.8″	+ 0.321 W	− 3.384 W	0	+ 0.321 W	− 3.384 W	3 706 W
0.0″	+ 0.9″	+ 0.321 W	− 7.088 W	0	+ 0.321 W	− 7.088 W	7.410 W
− 0.1″	+ 0 8″	− 0 249 W	− 2.087 W	− 1.062 W	+ 0.236 W	− 2 572 W	2 808 W
− 0.1″	+ 0.9″	− 1.428 W	− 1.430 W	− 1.556 W	+ 0.127 W	− 2.985 W	3.112 W
− 0.2″	0.0″	+ 0.273 W	− 0.866 W	0	+ 0.273 W	− 0.866 W	1.139 W
− 0 2″	+ 0.2″	+ 0.262 W	− 0.896 W	− 0.095 W	+ 0.269 W	− 0.904 W	1.173 W
− 0.2″	+ 0.4″	+ 0 213 W	− 0.986 W	− 0.231 W	+ 0.256 W	− 1.029 W	1.285 W
− 0.2″	+ 0.6″	+ 0 046 W	− 1.090 W	− 0.475 W	+ 0.219 W	− 1.262 W	1.481 W
− 0.2″	+ 0.8″	− 0 518 W	− 0.778 W	− 0.755 W	+ 0 118 W	− 1.415 W	1.533 W
− 0.2″	+ 0.9″	− 0 673 W	− 0.208 W	− 0.411 W	+ 0.031 W	− 0.913 W	0.944 W
− 0.3″	+ 0.8″	− 0.372 W	− 0.290 W	− 0 377 W	+ 0.048 W	− 0.710 W	0.759 W
− 0 4″	0.0″	+ 0.166 W	− 0.629 W	0	+ 0.166 W	− 0 629 W	0.794 W
− 0.4″	+ 0.2″	+ 0.142 W	− 0.621 W	− 0.113 W	+ 0.158 W	− 0.637 W	0.796 W
− 0 4″	+ 0.4″	+ 0 056 W	− 0 576 W	− 0.231 W	+ 0.132 W	− 0.651 W	0.783 W
− 0.4″	+ 0.6″	− 0.109 W	− 0.420 W	− 0.308 W	+ 0.081 W	− 0.610 W	0.691 W
− 0 4″	+ 0 8″	− 0.198 W	− 0.115 W	− 0.167 W	+ 0.016 W	− 0.328 W	0.345 W

By an equation similar to the third equation of (7), the angles made with the vertical by the lines of stress at the different points of the rollers may be computed from the values of P_r, Q_r and U_r in Tables Nos. 2 and 3. On the supposition that the lines of stress are arcs of circles, these angles would be given by the equation, $\cot. \Theta = \frac{y^2 - x^2 - r^2}{2\,xy}$ which is derived in the same way as equation (1). The angles have been computed by each of these methods for a large number of points in each roller, and the results are identical. This shows that the lines of stress are arcs of circles, as was suspected from the results of the polarized light experiments. It should be possible to prove this algebraically from equations (11), but the writer has not succeeded in doing so.

That the distribution of stress in a bridge roller is of the general character shown by Plates XVI and XVII and equations (11) was confirmed in an interesting way by some experiments made at Cornell University in 1893 by Prof. C. L. Crandall and the writer. In the 300 000 lbs. testing machine of Sibley College, rollers of tool steel, 1 in. long and respectively 1 in. and 2 ins. in diameter, were pressed be-

tween bars of the same metal, 1 in. wide by ¾ in. thick, as shown in Fig. 6. The sides of the bars were polished, and light was reflected on them from a mirror. As the elastic limit was passed, a line bounding the permanently distorted area made its appearance on each bar. The general shape of these lines, as well as the manner in which they shifted as the load increased, is shown by the dotted lines on Fig. 6. Allowing for the widening of the surface of contact between the roller and plate when the elastic limit was passed, due to the permanent indentation, it will be seen that these lines are of the same general shape as the color bands of Plates XVI and XVII.

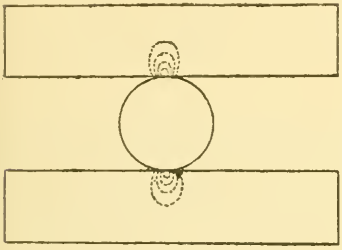


Fig. 6.

Under very great pressure the ends of the bars in the above experiments bent away from the surfaces on which they rested, and lines similar to those above described extended from the farther surface of each bar to meet the first lines.

The effect of the high loads put on these rollers was greatly to flatten them out, and to cause them to indent deeply into the bars. Finally, under a load of 168 000 lbs., the 1-in. roller began to shear through the bar.

It now remains to utilize the results of the preceding discussion in the derivation of a practical formula for the safe loads on bridge rollers.

There have been three practical formulas proposed, viz.:

$$W_s = C' \sqrt{d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

which is the formula generally used in bridge specifications in this country;

$$W_s = \tfrac{4}{3}\sqrt{2\, w_s^3\, r \left(\frac{r}{E_r} + \frac{r'}{E_p}\right)} \quad \ldots\ldots\ldots\ldots\ldots (13)$$

which is originally due to Grashof, but has been modified by Profs. Burr, Johnson and Eddy;*

and

$$W_s = Cd \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

which is the formula commonly used in Germany.

In the above formulas, W_s = the safe load per unit of length of roller, w_s = the safe stress in the roller or plate, r' = the thickness of

* See Burr's "Stresses in Bridge and Roof Trusses," pages 443-46.

the plate, r = the radius, and d = the diameter of the roller, E_r and E_p are the moduli of elasticity of the roller and plate respectively, and C' and C are empirical constants.

For equation (12) there is a theoretical derivation based on the assumption that the safe load will cause a certain fixed indentation of the plate for all diameters of rollers. Recently, also, Prof. Johnson has supported it on the ground that it is confirmed by the results of Profs. Crandall's and Wing's experiments with rollers 1 in. to 4 in. in diameter.*

The writer finds, however, that the results of these experiments will agree almost equally well with several different assumed formulas, and, in fact, they do not include a sufficient range of diameters to eliminate the effect of the irregularities of the tests. The results of these experiments are platted on Plate XVII.

Equation (13) is based on the supposition that the whole of the stress in the roller is borne by the strip included between the verticals through the edges of the area of contact. A glance at Plates XVI and XVII, or at Tables Nos. 2 and 3, will show that this assumption is very far from the truth. Moreover, this formula would make the crushing load depend upon the thickness of the plate. That this is incorrect was shown by experiments made in 1893 by Mr. G. E. McKim, at the Iowa State Agricultural College. He determined the crushing loads for 1-in., 2-in., 3-in. and 4-in. steel rollers, bearing on plates 2 ins. thick, cut from the same piece of steel as the rollers, and then had the plates planed down to successive thicknesses of 1½ ins., 1 in. and ½ in., repeating the test with each thickness. The results showed no appreciable variation of the crushing loads for different thicknesses of plates, although for the 1-in. roller equation (13) would make the crushing load nearly 67% larger for the 2-in. than for the ½-in. plate. Mr. McKim's results are given in Plate XVIII.

When, in equation (13), r' is assumed equal to r, the resulting equation is of the form given in (14). This is the form used for practical purposes in Germany, as already stated. It is evident, however, that the assumption that $r = r'$ could not be correctly made for any great range of diameters of rollers, and Prof. Johnson, in a discussion before this Society,† has shown that the derivation of (14) from the Grashof formula cannot be accepted.

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* See "Framed Structures," pages 273–77.

† See *Transactions*, Vol. XXI, page 206.

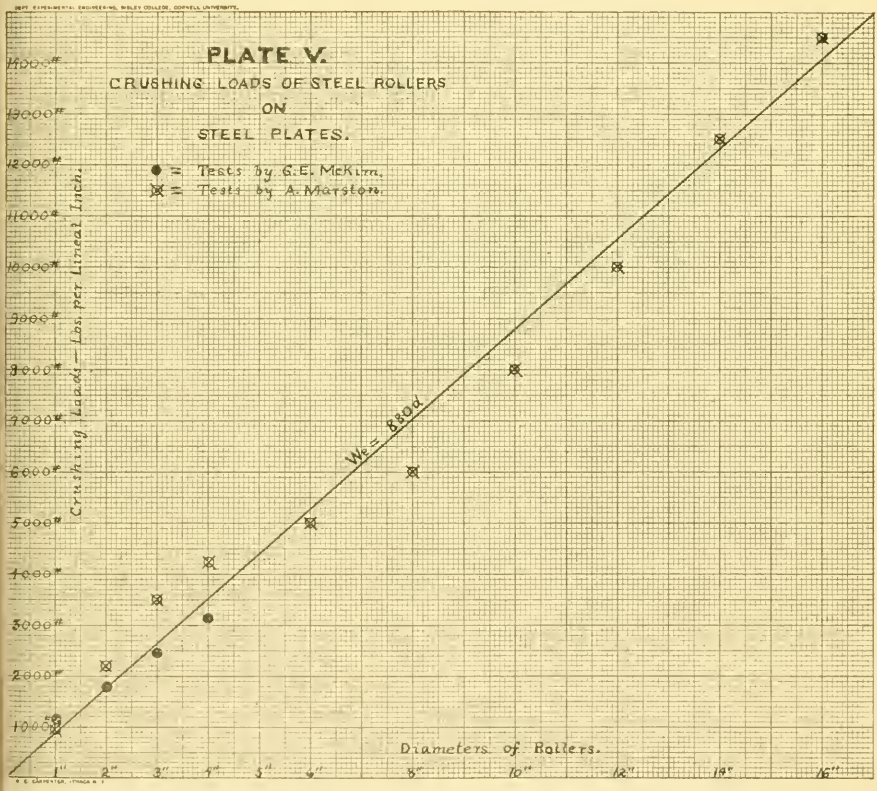
PLATE V.
CRUSHING LOADS OF STEEL ROLLERS
ON
STEEL PLATES.
● = Tests by G.E. McKim.
⊠ = Tests by A. Marston.
Crushing Loads — Lbs. per Linear Inch.
14000#
13000#
12000#
11000#
10000#
9000#
8000#
7000#
6000#
5000#
4000#
3000#
2000#
1000#
We = 800d
Diameters of Rollers.
1"
2"
3"
4"
5"
6"
8"
10"
12"
14"
16"

The results of the solutions given in this paper for the stresses in the roller and bearing plate may, however, be utilized to give a rational basis for formula (14), as follows:

The displacements and stresses in (5) and (11) are strictly correct for points near the middle of the roller (provided x and y for the plate are small in comparison with the length of the roller) for a uniform distribution of pressure, W per unit of length, along a *line* of contact. In the actual case, the force W is distributed over an *area*, instead of along a line of contact. From the theory of "local perturbations" (see Love's "Theory of Elasticity," page 259), it is evident that the displacements and stresses of (5) and (11) will still hold true for all points except those very close to the area of contact. It is also evident that the pressure between the plate and roller is a maximum at the middle of the area of contact, and is 0 at the edges of that area, so that the greater part of W is applied near the middle of the area of contact. Hence the equations (5) and (11) may be assumed approximately correct up to the edges of the area of contact.

Let the middle line of the area of contact be taken as the axis of Z, let the axis of X for the plate lie in the surface of the plate before it is strained, and let the axis of X for the roller be tangent at the origin to the roller before it is strained. Before the strain the surface of the plate will be the plane $y_p = 0$. After the strain it will be the surface $y_p = \frac{W}{\pi} c_p \log. \frac{l^2}{x^2}$ (see 5), where $c_p = \frac{(1+\sigma_p)(1-\sigma_p)}{E_p}$. For small values of x, the surface of the roller before strain will be $y_r = -\frac{x^2}{d}$ and after strain it will be $y_r = -\frac{x^2}{d} - \frac{W}{\pi} c_r \log. \frac{d^2}{x^2} + \frac{2W}{\pi} c_r$ (see 11), where $c_r = \frac{(1+\sigma_r)(1-\sigma_r)}{E_r}$. The edges of the area of contact will be where $\frac{dy}{dx}$ for the plate, equals $\frac{dy}{dx}$ for the roller; *i. e.*, where—

$$-\frac{2W}{\pi} c_p \frac{1}{x} = -\frac{2x}{d} + \frac{2W}{\pi} c_r \frac{1}{x}.$$

Hence, if x_a = the value of x at the edge of the area of contact, and A = the width of the area of contact,

$$x_a = \sqrt{\frac{c_r + c_p}{\pi} Wd},$$

and

$$A = 2\sqrt{\frac{c_r + c_p}{\pi} Wd}, = K\sqrt{Wd} \ldots\ldots\ldots (15)$$

where K is a constant.

Since equations (5) and (11) are only approximately true up to the edges of the area of contact, K may be considered to be an empirical constant to be determined by experiment. To ascertain how close K probably approximates to $2\sqrt{\frac{c_r + c_p}{\pi}}$, the writer has computed A on the supposition that the distribution of the pressures over the area of contact is such that they can be represented by the ordinates to a parabola, as is assumed in the derivation of the Grashof formula. The result was that K for this case $= \sqrt{\frac{3}{2}} \times 2\sqrt{\frac{c_r + c_p}{\pi}}$, and the formula was still of the form (15).

The writer has compared formula (15) both with the measurements of the area of contact taken by Professors Crandall and Wing, and also with the results of a similar series taken by Mr. G. E. McKim, under the direction of the writer. Mr. McKim used three independent methods: First, by placing a sheet of impression paper between the plate and the roller; second, by injecting coralline dissolved in ether around the roller after the load was applied; and, third, by placing a coating of tallow on the plate before the load was applied. The results are given in Table No. 4.

TABLE No. 4.

SHOWING MEASUREMENTS OF AREAS OF CONTACT BETWEEN ROLLERS AND PLATES.

	Load on Roller 1½ ins. long.	Area of Contact.		
		By impression paper.	By ether and coralline.	By tallow.
	Lbs.	Ins.	Ins.	Ins.
1-in. roller	500	.0238	.0370	.0257
	1 000	.0370	.0383	.0305
	1 500	.0435	.0397	.0340
2-in. roller	500	.0435	.0487	.0338
	1 000	.0516	.0501	.0372
	1 500	.0538	.0523	.0395
	2 000	.0550	.0545	.0433
	2 500	.0575	.0570	.0472
3-in. roller	500	.....	.0515	.0411
	1 000	.0494	.0532	.0429
	1 500	.0524	.0549	.0464
	2 000	.0545	.0563	.0498
	2 500	.0565	.0575	.0530
	3 000	.0587	.0587	.0558
	3 500	.0610	.0601	.0590
4-in. roller	500	.....	.0541	.0461
	1 000	.0547	.0554	.0490
	1 500	.0573	.0567	.0522
	2 000	.0592	.0580	.0555
	2 500	.0615	.0592	.0578
	3 000	.0640	.0607	.0605
	3 500	.0664	.0618	.0635
	4 000	.0685	.0632	.0660
	4 500	.0700	.0645	.0685

The measurements in the above table are each the averages of two measurements, one on the plate, and the other on the roller. Formula (15) with K equal to $2\sqrt{\frac{c_r + c}{\pi}\,p}$, gives in every case results very much smaller than the measurements in Table No. 4, or than those by Professors Crandall and Wing. The writer thinks that this should be the case. Taking Mr. McKim's results with tallow as an illustration, if formula (15) is correct and K is taken equal to $2\sqrt{\frac{c_r + c}{\pi}\,p}$, the thickness of the tallow films at the edges of the areas he measured would be only about .00015 in., this thickness being remarkably constant for the different measurements, although the areas were more than twice those given by (15). It is evident that the eye in attempting to locate the limits of so thin a film of semi-transparent material, gradually diminishing to 0 thickness at the edges of the area of contact, would be apt to choose a place where the film is of appreciable thickness, as the theory indicates was done. Indications were not wanting in Mr. McKim's experiments, as the writer watched them, that the true area of contact was very much smaller than the one measured.

Assuming equation (15) to be correct, a formula for the crushing load may be derived by placing the average load over the area of contact equal to the average stress at the elastic limit of the metal of the roller or the plate, whichever fails sooner.

In a case of compound stress like the one under consideration, however, the elastic limit stress will not be the one determined by observations with pieces of metal subjected to simple stress in the ordinary way, but a very much higher limit, as all measurements of the area of contact have shown (compare Table No. 4), though such measurements are known to give average pressures smaller than the true pressures. The reason for this raising of the elastic limit was clearly stated by Mr. J. B. Francis, in the discussion of the paper on "Cylindrical Wheels and Flat Topped Rails," in Vol. XXI of the *Transactions*.* It has been questioned whether the value of the elastic limit stress for rollers will not vary for different diameters of rollers. The writer finds, however, by experiments covering a greater range of diameters than any heretofore made of which he has been able to

* See, also, the discussion by Professor Johnson, page 273, of "Framed Structures."

find record, that the average stress per unit of the area of contact of bridge rollers at the elastic limit is constant.

Call this stress w_e. By equation (15) the average stress over the area of contact, A, is $\frac{W}{A} = \frac{\sqrt{W}}{K\sqrt{d}}$, which at the elastic limit becomes $\frac{\sqrt{W_e}}{K\sqrt{d}}$, where W_e is the crushing load per unit of length of roller. Putting this equal to w_e, the average stress in the metal at the area of contact for the elastic limit,

$$W_e = K^2 w_e^2 d = C d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

where C is an empirical constant to be determined by experiment. If W_s be the safe load per unit of length of the roller,

$$W_s = \frac{1}{f} \times C d \ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

where f is the factor of safety used.

Although the writer has made a close search in all the technical literature to which he has access, he has not succeeded in finding any data as to the bearing strength of bridge rollers as determined by actual experiment, other than those of the experiments of Professors Crandall and Wing. In these, as has already been said, the range of diameters was not sufficient to eliminate the irregularities of the tests. The same is true of the experiments by Mr. McKim, to which reference has already been made. The lack of experimental data relating to the subject has led the writer to undertake a series of experiments to determine the effect of the diameter of the roller on the crushing loads of bridge rollers, the results of which, together with those of Mr. McKim's experiments, are platted in Plate XVIII.

Mr. McKim's experiments were made with rollers 1, 2, 3 and 4 ins. in diameter and 1½ ins. long, all cut from a piece of round steel 4½ ins. in diameter, obtained from the Illinois Steel Company. The bearing plates were 4 ins. square, and of different thicknesses, as already described. The lower plate, on which the observations were made, rested on a block of limestone 6 ins. thick. A chemical analysis of the steel gave the following results: Silicon, trace; phosphorus, 0.089%; sulphur, 0.135%; manganese, 0.507%; carbon, 0.370 per cent. The modulus of elasticity of this material, as determined by a compression test on a piece 1 x 1 x 10 ins. between caliper points, was 28 900 000 lbs. per square inch. The elastic limit stress, and the tensile strength, as determined by a test of a piece ¾ in. square, were, respectively, 31 000 lbs.

per square inch and 50 000 lbs. per square inch. The reduction of area at the fractured section was 31%, and the elongation in 8 ins. was 21 per cent. The crushing loads per lineal inch of roller are platted in Plate XVIII.

The writer's experiments, which have just been completed, were made with rollers 1, 2, 3, 4, 6, 8, 10, 12, 14 and 16 ins. in diameter, and 1 in. long, all cut from one steel plate by the Clinton Bridge and Iron Works, of Clinton, Ia. The bearing plates were 6 ins. square x 0.9 in. thick, cut from the same plate as the rollers. A chemical analysis of the steel gave the following results : Silicon, phosphorus and sulphur, a trace of each ; manganese, 0.61 %; carbon, 0.24 per cent. The modulus of elasticity, as determined by a compression test of a piece 0.607 x 0.618 in. x 8½ ins. between caliper points, was 27 300 000 lbs. per square inch. The elastic limit stress was 36 000 lbs. per square inch; the tensile strength, 58 000 lbs. per square inch ; the elongation in 5 ins., 31%, and the reduction of area of the fractured section, 60%, a test piece, 0.607 x 0.618 in. being used. The rollers were polished and the plates surfaced. The tests were made on a 50 000-lb. Olsen testing machine, at the Iowa State Agricultural College.

The elastic limit load for rollers bearing on plates is hard to determine very definitely, because the first permanent indentation is not perceptible to the eye unless the plate is held to the light in a favorable position. In these experiments the load at the elastic limit was determined by applying loads increasing by small increments from a safe value, and making a careful examination of the plate and roller after each load was applied, until a permanent indentation could be detected on the plate. In no case could a permanent mark be detected on the roller as soon as on the plate, probably because the shape of the former is not so favorable for detecting very slight deformations as that of the latter.

The results of these experiments are platted on Plate XVIII, together with those obtained by Mr. McKim. While the results show irregularities, these are not greater than can be explained by unavoidable differences in the accuracy of finish of the rollers, or in the quality of the metal from different parts of the same plate. The writer considers that the results are as conclusive as those of any one set of experiments can be in favor of the formula $W_e = C\,d$. The average value of C for the writer's experiments is 880 lbs. per lineal inch of roller.

For comparison, the crushing loads per lineal inch of Professors Crandall's and Wing's experiments are platted on Plate XIX, omitting those for the 4-in. wrought-iron roller, which were uniformly smaller than those for the smaller diameters of rollers of the same kind of material, because this fact would indicate a poor finish or a poor quality of material in the roller. It will be seen that the results were very irregular. Part of these irregularities was probably due to the fact that comparatively large increments of load were used in the tests, and part to differences in the accuracy of finish, or in the quality of the metal of the plates and rollers. The average lines for the different metals are drawn on the plate, assuming formula (16) to be correct. A careful study of Plate XIX will show that the experiments conform to this theory as well as to any other. The value for C for wrought iron and steel is much larger than the one determined by the writer's experiments.

If the formula $W_s = \frac{1}{f} C\,d$ be accepted as correct, there are strong reasons for changing the ordinary accepted bridge specifications to conform to it, which have been stated by Mr. George S. Morison in a recent paper, read before the American Society of Mechanical Engineers. The rule that the safe loads vary as the square root of the diameter of the roller encourages the use of small rollers, making the rolling friction greater, and causing greater danger of the expansion bearings becoming immovable through imperfections of workmanship, or other causes. Probably every bridge engineer can recall instances of his own observation, where the expansion bearings of bridges have proved, on inspection, to be in this condition. The rule that the safe load varies as the diameter will, when taken in combination with the use of segmental rollers, make it possible to obtain an economical expansion bearing with rollers of large diameters, and thus help to avoid this defect. Moreover, this rule is not an untried one, but has been used abroad.

In assigning the proper value for the factor of safety to use in this formula, account should be taken, on the one hand, of the fact that the pressure is seldom equally distributed over the roller by the ordinary end shoe of a bridge, and, on the other hand, of the fact that an excessive pressure on the roller is not so fatal a defect as it would be in other members of the bridge. Mr. George S. Morison uses in his practice the formula

$$W_s = 250\,d \qquad (18)$$

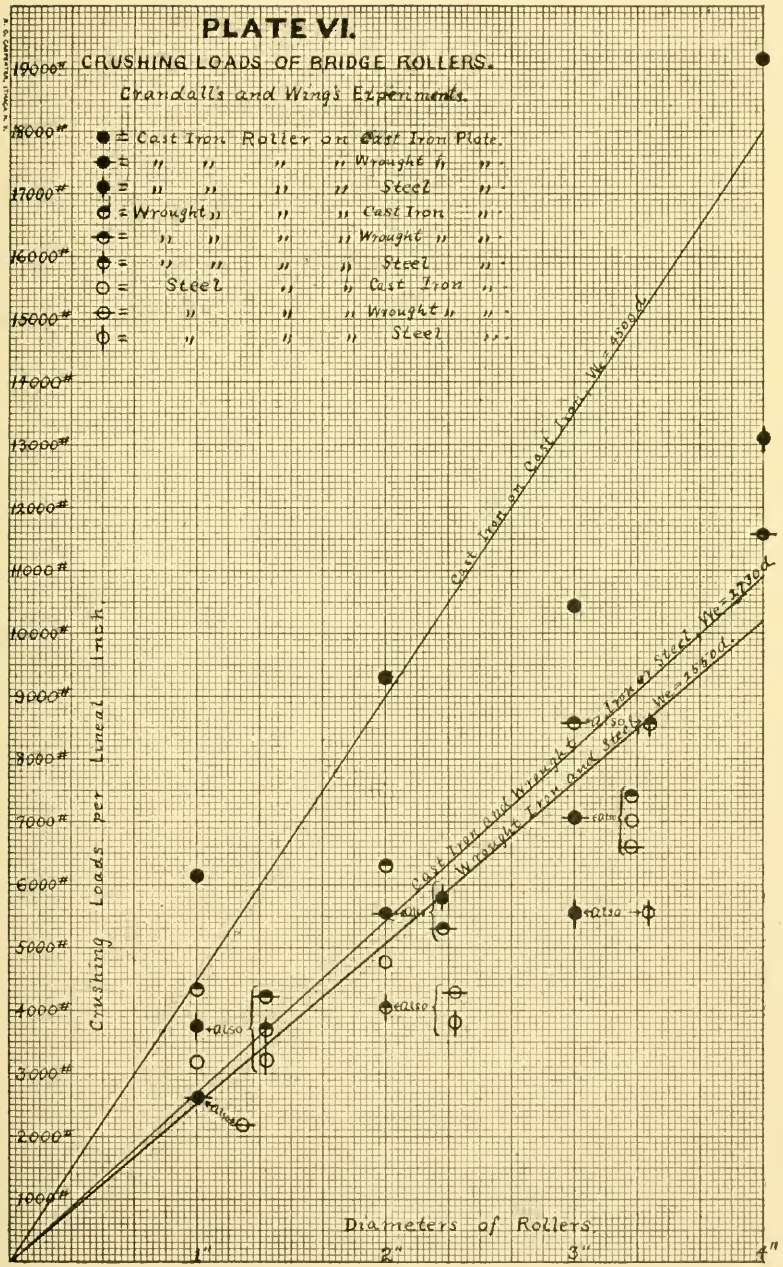
PLATE VI.
CRUSHING LOADS OF BRIDGE ROLLERS.
Crandall's and Wing's Experiments.
= Cast Iron Roller on Cast Iron Plate.
" " " " Wrought " " "
" " " " Steel " "
= Wrought " " " Cast Iron " "
" " " " Wrought " " "
" " " " Steel " "
= Steel " " Cast Iron " "
" " " " Wrought " " "
" " " " Steel " "
Cast Iron on Cast Iron. We = 4900#
Cast Iron and Wrought on Steel. We = 2750#
Wrought Iron and Steel. We = 1580#
+also
Crushing Loads per Lineal Inch.
Diameters of Rollers.
19000#
18000#
17000#
16000#
15000#
14000#
13000#
12000#
11000#
10000#
9000#
8000#
7000#
6000#
5000#
4000#
3000#
2000#
1000#
1"
2"
3"
4"

where W_s is the safe load in pounds per lineal inch of roller, and d is the diameter of the roller in inches. For a 4-in. roller this gives the same value for W_s as the ordinary formula $W_s = 500 \sqrt{d}$.

For the writer's experiments, with rollers and plates of mild steel, formula (18) corresponds to a safety factor of 3½, which would certainly be sufficiently large; and the formula may be supported for all cases, on the ground that cast-iron or hard-steel rollers and bearing plates require a larger factor of safety than those of wrought iron or mild steel.

DISCUSSION.

W. R. Hutton, M. Am. Soc. C. E. (by letter).—In addition to the observations upon glass under stress viewed by polarized light which are mentioned by Professor Marston, a very interesting series by Mr. A. Leger is illustrated and discussed in the memoirs of the Society of Civil Engineers of France for 1879. It has but slight bearing upon the particular form of stress under discussion here. Referring, however, to the double or triple iridescent ellipses at the point of maximum pressure, Mr. Leger observes that the glass scales off along the contours of these ellipses with undulated surfaces, and after rupture these surfaces are seen to be wavy and wrinkled (*ridé*) in conformity with the last polarized figures of the unbroken glass; and "jets" of striæ traverse these undulations in the direction of the "diffusion" of the interior forces; these waves mark the limit-deformation which precedes rupture.

I have not seen the paper in the *Physical Review*, as there is no copy of it in the library of our Society.

Besides the "practical" formulas for safe loads on bridge rollers on page 119, the following approximate rule, which I copy from Résal (*Ponts Métalliques*, page 92), for roller and plate of the same material, although it takes no note of the conjugate stresses, is based upon sound theory and is at the same time eminently practical.

Let d = diameter of roller.
a = half chord of indentation.
b = versed sine of same.
c = unit pressure on center line of contact (maximum unit pressure).
E = modulus of elasticity.

Assume, as is commonly done, that half the indentation is the compression of the roller at the point of contact:

$$c\,\frac{d}{2} = E\,\frac{b}{2} = \text{very nearly } E\,\frac{a^2}{2d};$$

The whole compression $= F = \frac{2}{3} c \times 2a$; combining and eliminating a,

$$F = \frac{16}{9} d^2 \frac{c^2}{E}$$

$$F = \frac{4}{3} dc \sqrt{\frac{c}{E}}$$

$$\frac{F}{d} = \frac{4}{3} c \sqrt{\frac{c}{E}}.$$

The stress in the roller, therefore, varies directly as the diameter. The maximum unit pressure c of the roller on the plate must not exceed the elastic limit of the material. If, with Résal, we assume a factor of safety of one-half, we find for steel with an elastic limit of 30 000 pounds to the square inch, and $E = 27\,000\,000$, $F = \frac{4}{3} d\, 15\,000 \times \sqrt{\frac{15\,000}{27\,000\,000}} = 471d$ in pounds per lineal inch of roller. Mr. Morison's formula therefore is well within safe limits, and corresponds to a factor of safety of one-third, or a maximum pressure of one-third the elastic limit. These results also appear to coincide with Professor Marston's observations.

For cast iron, however, contrary to Professor Marston's conclusions, a much greater weight per linear inch of roller for the same diameter may be permitted.

C. L. Crandall, M. Am. Soc. C. E.—In connection with the remarks by Professor Marston, on page 126, in regard to the elastic limit of the rollers given on Plate XIX, it should be stated that the experiments were primarily for surface or contact rather than for elastic limit. Still, whenever either roller or plate was indented sufficiently to be apparent to the eye the fact was noted, as it was desired to keep within the elastic limit.

The following abstract of an article published in "Annales des Ponts et Chaussées," June, 1893, by M. H. Deslandres, describing some experiments upon the deformation of plates and rollers under compression, will be of interest in this connection as showing the amount of permanent set which takes place with small loads, and the point at which this set begins to increase much faster than the load.

Three rollers were used, each 200 mm. (7.87 ins.) long; the first, of cast steel, was 240 mm. (9.45 ins.) in diameter; the second, of cast iron, was 120 mm. (4.72 ins.) and the third, of cast iron, was 160 mm. (6.30 ins.) in diameter. The plates were all cast iron, 200 mm. (7.87 ins.) wide, and 80 mm. (3.15 ins.) thick.

Seven equidistant sections were marked upon the rollers and plates, and the compressed diameter at each section of the roller was compared with the diameter at an angle of 45° with it by a calliper scale

divided to hundredths of a millimeter (0.0004 in.), which was capable of being read with a maximum error of $\frac{2}{1000}$ mm. The indentation of the plate with reference to the surface on each side of the line of contact was measured at each of the seven corresponding sections by a plane-tester reading to the same fineness.

With the steel roller the permanent deformation is only given for a small range of loading, for which range it is constant and nearly zero.

For the plates compressed by the steel roller the permanent indentation begins with a load of 0.25 kgr. per square millimeter of diametrical section, = 356 lbs. per square inch, = 3 360 lbs. per lineal inch of roller, and increases directly with the load to 0.833 kgr. per square millimeter, = 1 185 lbs. per square inch, = 11 200 lbs. per lineal inch, for which the indentation = 0.45 cu. mm. = 0.0002 in. The next increment of 25% to the load increases the indentation over 120%, passing what the author calls the critical pressure.

For the small cast roller, the deformation is proportional to the load up to 1.042 kgr. per square millimeter, = 1 482 lbs. per square inch, = 7 000 lbs. per lineal inch of roller, for which the diameter is shortened 0.45 cu. mm. = 0.0002 in.

The next increment of 20% to the load adds 73% to the deformation.

For the large cast roller, the deformation is proportional to the load up to 0.443 kgr. per square millimeter, = 630 lbs. per square inch, = 3 970 lbs. per lineal inch, for which the diameter is shortened 0.30 cu. mm., = 0.0001 in. The next increment of 41% to the load adds 123% to the compression.

The author concludes that 0.44 kgr. per square millimeter is the theoretical limit for the cast rollers, giving a deformation not over $\frac{1}{30000}$ of the radius, while in practice he would limit the safe load to 0.22 kgr. = 313 lbs. per square inch of diametrical section.

For cast plates with steel rollers he places the limit $\frac{1}{5}$ less, or 0.18 kgr. = 256 lbs.

These values are slightly in excess of the 250 d of equation (18) used by Mr. George S. Morison.

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TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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THE QUALITY OF WATER SUPPLIES.

By JOHN W. HILL, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

The presentation to the Society of a paper on the self-purification of streams, by Dr. Charles G. Currier,* and one on fresh water algæ, by George W. Rafter,† M. Am. Soc. C. E., is the writer's apology for offering a paper on a subject, which, from its title, might seem better addressed to a health congress than to a society of engineers. But health boards and medical societies are usually powerless to rectify the evils to which attention is called by this paper. They may raise objections to existing conditions, and propose remedies, but to the engineer is finally entrusted the work of design and construction. Moreover, if the engineer engaged on a work of public water supply makes no mistake in selecting the source, or, the source being open to suspicion, he adopts the proper remedies to avoid injury to the consumers of water, then no question can be raised by health boards and medical associations. After all, it seems that health officers, physi-

* Trans. Am. Soc. C. E., Vol. XXIV, page 21.

† Trans. Am. Soc. C. E., Vol. XXI, page 483.

cians and analysts of water supplies can only demonstrate the evils, and aid the engineer in determining the cause, while the processes or devices for meeting or avoiding the danger are purely engineering problems, and as such should always be worthy of attention at our hands.

To members of the Society engaged in designing or operating works of public water supply, any inquiry into the quality of drinking water is usually always welcome, and, while the writer does not expect to offer any new facts, he hopes to be able to present some of the old ones in a way to carry conviction to doubting minds, of one of the principal dangers which now invests our sources of drinking water.

It is believed that water is a carrier of certain diseases, namely, cholera, typhoid fever and diarrhœa, and that the specific germ is transmitted from the sick to the well through the medium of drinking water.

It is also held by some investigators that the breaking up of vegetable detritus in drinking water may be the cause of disease, and it is well known that mineral poisons may be imbibed in drinking water.

Cholera is said, by Dr. Shakespere and others, to originate *de novo* in India, from the contamination of their drinking water by the filth of the native inhabitants,* and epidemics of typhoid fever and diarrhœa have been traced to wells,† or other sources of water supply, or to the ice used in cooling water,‡ the germs of disease being locked up in the ice and released upon its melting in the water.

Now, while water is held to be a carrier of disease germs, the writer is not aware that any investigator has ever claimed to have seen these germs in water, even under the highest powers of the microscope; and the evidence that water is such a carrier of pathogenic bacteria is obtained by inoculation from water samples, of nutrient media in test tubes, or on culture plates.

Thus, by methods quite indirect and open to grave errors of judgment in the hands of any but an expert, the fact of water carrying the spores of disease germs is established.

To those who have given the subject of bacteria no special study, it is proper to remark that the modern methods of bacteriology have

* "U. S. Rep. on Cholera in Europe." Dr. Edward O. Shakespere, 1890.

† "Bacteriological Study of Drinking Water." Dr. Victor C. Vaughan, Ann Arbor, Mich., 1892.

‡ "Water Supply." W. R. Nichols, 1883.

clearly proven that the soil, air and water swarm with bacterial life, and that countless micro-organisms and presumably organisms which cultivation and the microscope have not yet revealed, are steadily at work feeding upon and destroying the organic matter in these elements, and that we who drink water and inspire air are taking into the system thousands of these bacteria or their spores every day of our lives, from which it follows that first, all these bacteria are not pathogenic in character; or, second, the condition of the circulation or tissues of the human system are such as to repel their action and deprive them of a fertile soil, both of which are known to be true.

Of the so-called pathogenic bacteria, only a few have been proven to be the cause of disease, and of those which are known to accompany disease, although they may not cause it, they are said to be only active when brought in contact with a vitiated circulation, or with surface or internal lesions.

There can be no blood poisoning, excepting the germ of "septicæmia" be introduced into the circulation, and it can be introduced into the circulation only through a lesion of the skin or membrane.

So long as water contains organic matter in process of destruction, so long will bacteria be present in water, and some of these may be pathogenic bacteria, and lay the foundation for dangerous disease.

In considering the number of colonies of bacteria per unit of volume in a given water sample, it has been assumed that the number bears a just relation to the amount of organic matter in such water, and that any treatment of the water which diminishes the number of colonies of bacteria really does this by reducing the quantity of organic matter upon which such bacteria subsists. If all the bacteria, by any process, are removed from a sample of water, it is held that such water has been wholly deprived of organic matter, and, conversely, bacteria or other organisms harmless or harmful (to human life) cannot survive in a water wholly deprived of organic matter in a state of dissolution. It is possible that an absolutely pure water might be the carrier of a disease germ which accidentally came into it, but it is not likely that such germs could long subsist in a water deprived of pabulum for them, and they would soon perish for lack of subsistence, for bacteria, like any other vegetable growth, must have the proper nourishment, to sustain life.

The simple knowledge that organic matter exists in water, without

a knowledge of its source, is not worth much. Sugar is organic matter; so is excreta. Sugar in water would not be considered dangerous; excreta in water would be highly dangerous. Any organic matter in water will show an excess of ammonias above the normal, whether this be derived from safe organic compounds or from decomposing wastes; hence, a knowledge of the organic matter, independent of the knowledge of the kind of source of such matter, does not furnish reliable information upon the quality of a water sample. The chemical test for chlorine is usually relied upon to determine the probable source of organic matter, chlorine, usually from animal urine, indicating a sewage origin.

In classifying waters from high elevations, where the probabilities of sewage contamination are small, and waters from lowland sources, where the probabilities of sewage contamination are large, Prof. Frankland considers that the source or cause of pollution is more important than pollution itself, and proposes that waters from elevated sources may contain from one and one-half to twice the amount of organic elements (organic carbon and organic nitrogen) of lowland waters and still rank with the latter of any class (Frankland's "Analysis of Waters," page 94).

PARTS PER 100 000 OF ORGANIC ELEMENTS IN WATER.

Class.	Upland source.	Lowland source.
1. Water of great purity....	0.2	0.1
2. Water of medium purity.....	0.2–0.4	0.1–0.2
3. Water of doubtful purity.....	0.4–0.6	0.2–0.4
4. Impure water.....	0.6 +	0.4—

The bodies of fresh water at lowest elevation of any geographical system are the rivers and lakes, and these are essentially the channels of discharge for the sewage of organized communities, as well as for that larger volume of decomposable wastes in the surface drainage from urban and agricultural territory; hence, organic matter in lowland waters, whether of rivers or lakes, is generally from sewage or semi-sewage sources, while organic matter in the waters gathered at high elevations is generally the result of vegetable detritus in the run-off of rainfall on unimproved or virgin water-sheds.

Chemistry enables us to determine as compounds containing nitrogen the organic matter in solution, while the microscope assists us in

the examination of the organic matters in suspension, but in doing so it has this advantage over chemistry, in that the examination is direct and not so much dependent on the personal equation as the results of chemical analysis.

A sample of rich sewage under microscopical observation will show micro-organisms capable of identification, together with masses of loose flocculent matter, which some term amorphous matter, but which the writer has indicated in his notes of tests as broken-up albuminous and cellulose matter. Such a sample, under continuous examination, will show a reduction of this loose matter, and in due time it will altogether disappear, the micro-organisms absorbing it, to support life; and with the disappearance of organic matter, there is a reduction of the vegetable and animal life in the water sample.

It is sometimes asserted that certain organisms are only found in good water, but the writer has observed, for instance, *Copepoda* in good cistern water, as well as in water known to be defiled by household wastes. If *Copepoda* alone were found in a water sample, the writer should not regard it as bad; but if associated with other and lower animal organisms and the lower kinds of filamentous algæ, he would consider such water as unsafe for drinking purposes. What is true of this particular organism, which is commonly found in soft waters, is true of any other organism supposed to inhabit pure water.

In order to approach the question of water pollution properly, it must be borne in mind that while polluted water is held to be the cause of certain diseases, exactly how it acts on the human system is not well known. Bacteriologists generally regard the Koch cholera bacillus, and the Eberth typhóid bacillus, as the causes of these diseases, but this view is not shared by all physicians as it should be if the proof of cause was sufficient, although common prudence should decide us in rejecting any water known to contain the cholera or typhoid bacilli, whether these germs be regarded as the cause or result of disease, since they indicate the presence of the cause if not the cause themselves.

The presence of putrefactive bacteria in a water sample is an evidence of decomposition going on in the water, but the disease, if any be derived from the use of such water, may not be due to the bacteria at all, but to some ptomaine obtained from the decomposition of the or-

ganic matter, or, as Professor Vaughan terms it, to some "toxicogenic" property of the water.*

While water may be a carrier of the cause of cholera, diarrhœa and typhoid fever, it is only the latter in which we are specially interested. Cholera may never arise *de novo* in this country, and diarrhœa traceable to a polluted water supply is seldom fatal, while typhoid fever is with us always, and, apparently, in all localities, and its ravages of the young, the bright, and the promising, are more to be dreaded than any of our infectious diseases, if we may except diphtheria, and, in the writer's opinion, it is more dreadful than diphtheria, because the latter is usually confined to the very young and undeveloped, while typhoid strikes down its victims as it were when they are on the very threshold of life; and, in discussing the danger of a polluted water supply, it will be from the single standpoint of its influence in the propagation of typhoid fever; although it may be well to remark, that, apart from the specific germs or sources of the diseases mentioned, water may contain common putrefactive bacteria which may not be hurtful in themselves, but which indicate the probability of the presence of organic matter in some of which there may be danger.†

The pumping of water for domestic uses from a source known to be polluted by sewage or otherwise cannot be too strongly condemned. The delivery of water containing the elements of fatal disease to a confiding and helpless community, partakes, in the writer's opinion, of the worst kind of criminality, and no one engaged in such work who is aware of this, or who refuses to apply the tests which will reveal the danger, if it exists, can hope to escape censure, even if, for lack of laws, he may escape a just punishment for his crime.

An attempt to kill people by the systematic distribution of a deadly poison would be met by the prompt arrest and punishment of the offender, but the delivery of a water for domestic uses as fatal to some as a dose of strychnine is permitted without a word of complaint. Why is this? Must we shut our eyes to the fact that polluted water is dangerous to health? Must we reject the results of the work of the patient investigators who have demonstrated over and over again that danger, often death, lurks in our drinking water? Or shall we recognize the peril and address ourselves to the task of rectifying an evil

* "A Bacteriological Study of Drinking Water," by Dr. V. C. Vaughan, 1892.

† Parkes' "Manual of Practical Hygiene," 1883.

greater than any other connected with the art of engineering? For the saving of human life, whether accomplished by medical remedies or the sanitary arts, is the noblest work to which man can set his hand.

The difficulty of procuring a satisfactory supply of potable water for large or even small communities, is well understood by the engineers engaged in this line of work. Sources of supply, which 10 or 15 years ago were thought to be safe in a sanitary aspect, are now open to grave suspicions of quality; and it is not extravagant to assert that few of the larger cities of the country enjoy a public source of water supply which satisfies the ordinary requirements of a potable water.

The increased sewage pollution of rivers and lakes which might furnish a safe drinking water is partly responsible for the difficulties surrounding this problem. But, apart from the special sewage pollution by organized communities, there is a pollution of streams and lakes by the ordinary surface drainage from agricultural water-sheds which often renders the waters of such unfit for drinking purposes.

Several years ago in discussing this question, the writer took the ground that, as the proportion of water used for drinking purposes was ½ per cent., or less, of the whole quantity consumed by the takers from a public source, the better plan was not to attempt to secure the whole supply of potable quality, but to render any water available fit for drinking purposes by domestic filtration. Later experience satisfies him that this plan will not answer for several reasons:

1. All consumers of a public water supply cannot, or will not, use domestic filters.

2. There is no domestic filter which is absolutely proof against the dangers of polluted water.*

3. Even if a satisfactory filter was obtainable, it is doubtful if the average householder would give this the attention it would require to keep it at all times in condition to act as a safeguard.

In view of which the writer has reached the conclusion that, if the consumer is to have a safe drinking water, it must come to him in this condition through the public water mains. In other words, the matter of purity must be looked after by the municipal corporation, or the water company. The prevalence of typhoid fever in many cities and

* Parkes, "Practical Hygiene," 1892.

towns having a public water supply is evidence of the water now generally furnished to consumers as being unpotable, and that the municipal corporations, or the water companies, are furnishing to their consumers the spores, or organized bacilli of the Eberth germ, or material from which the specific virus of typhoid is generated.

In speaking of the typhoid bacillus in water, it should be remarked that this has never been seen with the microscope without previous cultivation of the germ in nutrient media. Nor has it ever been demonstrated, so far as the writer is aware, that the presence of bacilli in water can be proven, excepting by delicate and difficult bacteriological processes.* It is well understood that the infective element of typhoid fever can be present in water and the chemical test be powerless to disclose it.†

In his excellent treatise on Sewage Disposal, Mr. Rafter aptly remarks "that absolute immunity from danger (by sewage pollution of water supplies) cannot be hoped for. There will always be some risk, even after the best has been done that is possible in any given case. And, so far as public water supplies are concerned, the true remedy lies in the direction of an absolutely uncontaminated source."‡

The only objection that can be raised to Mr. Rafter's method of securing an undefiled water supply is the great difficulty of its general application. For small communities requiring but a few hundred thousand gallons of water per diem, a supply of potable water can often be had from deep driven wells; but for large cities using many millions of gallons daily, such a source of supply is out of the question. It is doubtful if the water gathered on inhabited and improved water-sheds and impounded in large reservoirs for city supply, can be regarded as absolutely safe water for drinking purposes. Neither is it proper that lakes without current or circulation, and often the receivers of city sewage, should be considered as undefiled sources of supply.

Rivers receiving the sewage of cities and towns on their banks, and on the banks of their tributaries, certainly are not within the limitation of Mr. Rafter's sources, and where, then, are we to obtain the large volumes of water daily required by our larger cities, and have the same free from contamination at its source? Cities located in the moun-

* Sternberg, "Manual of Bacteriology," 1893.

† Frankland, "Water Analysis," 1890.

‡ Sewage Disposal, by Geo. W. Rafter and M. N. Baker, 1894.

tainous regions can impound water at elevations so high as to avoid pollution from all sources but the atmosphere, and this, as well as water, is always purer than in the valleys and on the lowlands. But for the larger cities of the middle States, having no mountain sources within practical reach, and without visible sources of supply which will satisfy Mr. Rafter's requirements, our only resource is to accept such water as is available in large quantities, and so deal with it as to render it innocuous to health.

It is too frequently asserted or implied in text books and reports on sewerage, that the noxious properties of sewage are destroyed or safely mitigated by proper dilution, but if sewage should be the carrier, as it undoubtedly often is, of pathogenic germs, how can dilution remove them? It may reduce the number per unit of volume of the mixed sewage and water, but the germs are still there, and when taken into the system through drinking water, may produce just as serious results to just as many people as if no dilution had occurred. Dilution may reduce the chances of any single individual imbibing a fatal germ, but the germ itself will be just as dangerous when it is imbibed. In speaking of germs in this connection, it must be understood that they are not limited to organized bacteria, but are meant to include any toxic property of water which may be derived from a sewage source.

The common opinion that the number of germs in a water sample is an index of its potability is apparently not well founded; for instance, from Dr. Victor C. Vaughan's extensive and able investigation of Michigan's waters, we note, that water from Torch Lake, Mich., containing 5 284 germs per cubic centimeter in a beef tea solution was fatal to rats, and well water from the same place, containing only 20 germs per cubic centimeter in a culture of beef tea, was also fatal to rats. Both of these waters were suspected of being the cause of typhoid fever. River water from Mount Pleasant, Mich., containing 3 000 germs per cubic centimeter in a culture of beef tea, had no effect on rats, while artesian water from Gladwyn, Mich., containing 10 germs per cubic centimeter in the same culture, was fatal to guinea pigs. Lake water from Soudan, Minn., containing 459 germs per cubic centimeter in the same culture, had no effect on rats, while well water, also from Soudan, containing four germs per cubic centimeter in the same culture, was fatal to rats.* Of course, Dr.

* "A Bacteriological Study of Drinking Water," by Dr. V. C. Vaughan.

Vaughan's tables contain illustrations the opposite of these, but these demonstrate clearly that the number of germs is not a safe index of the quality of the water sample (see Sternberg's "Manual of Bacteriology," page 558).

What is desired is not so much that the germs be reduced to a small number, as it is to eliminate altogether those of a pathogenic character. A man in jumping a brook must accomplish the feat in one leap. He cannot jump half way across and rest, and then jump the other half at his convenience. So it seems to me in dealing with the subject of water purification; we cannot partially purify it, and then deliver it to the consumers, without great risk. The bacteria, or other cause of disease, must be wholly eliminated, or we will be in the predicament of the man who attempts to cross the brook in two jumps, we will be worse off than if we had remained on the hither side; for a partial purification of our drinking water will beget a feeling of security which is false and may lead to serious results, while no attempt at purification at all will leave us on our guard against a polluted water, and cause us to avoid the drinking of it altogether.

In reports of filters tested for the reduction of bacteria it is customary to state the condition of the water in bacteria per cubic centimeter before and after filtration. These are given as the average per cubic centimeter and often the number after filtration may be as low as three or four, and the writer has seen it stated as low as one per cubic centimeter. An ordinary drinking tumbler contains half a pint, or about 230 cu. cm., and with the best of filtrated water so low in bacteria as one or two per cubic centimeter, a person may imbibe from 250 to 500 bacteria in drinking a single glass of water, some of which may be pathogenic and produce typhoid fever, or some other less dangerous disease.

Heretofore the writer has concurred in the popular belief that ordinary filtration of polluted water through some of the well-known modern filters would render it reasonably safe for drinking purposes, but from recent investigations of his own he is compelled to abandon this view. In the case of Cincinnati, with which he is familiar, the public water of which is notoriously unfit for drinking, nearly every public house and many business establishments are supplied with some form of sand filter or with the Pasteur filter, and yet Cincinnati takes high rank for its number of cases and deaths from typhoid fever.

Dr. Frederick Kebler, a skillful bacteriologist and eminent physician, informs the writer that even the celebrated Pasteur filter is not proof against the passage of bacteria; that these attach themselves to the outside of the porous porcelain tube, and, by growth and fission, eventually appear upon the inside of the tube, and may be found in the filtered water; and, from the writer's own examination of a section of a Pasteur filter tube under the microscope, he conceives that the pores are large enough to pass bodies of considerable magnitude, *i. e.*, from a microscopic standpoint.

Filtration through a Pasteur tube can accomplish no nitrification by bacterial agency, and poisons, or the base of ptomaines in solution, are certain to be found in the filtered water.

It is said by the manufacturers that the porosity of a Pasteur filter is equivalent to 1 micron (u), or $\frac{1}{25000}$ in. Now, the average diameter or thickness of a typhoid bacillus is $\frac{1}{5}$ micron (u),* and the spores very much less.† From which it appears that the Pasteur filter tube is open to the unrestricted passage of the germs and their spores, if such should have a habitat in the water.

There being no nitrification in passing through a Pasteur tube, no change can possibly be effected in the organic matter in solution in the water. For this, as we understand, can only be accomplished by boiling, chemical reactions, or by the nitrifying action of bacteria. In this respect a sand filter, properly constructed and worked, should yield a better filtrate than a Pasteur filter. But, as sand filters are usually worked, it is probable that they not only fail to remove organic matter in solution, but some of that in suspension may pass through, the only test of the filtrate being its limpidity, and it is well known that waters may be clear as crystal and still contain much organic matter in suspension, and all it ever had in solution. Clear water may be very dangerous water, as witness some of the spring waters sold in Boston and vicinity recently tested by Prof. T. M. Drown.‡

The so-called sanitary tests of water by chemists, when unsupported by careful microscopic tests, and this again fortified or checked by tube and plate cultures from the water sample in question, cannot be accepted as proof of quality, since "the existence of an

* Cruikshank, "Manual of Bacteriology," 1890.

† Rafter & Baker, "Sewage Disposal," 1894.

‡ Twenty-third Annual Report, Mass. State Board of Health.

infectious property in water cannot be proved by chemical analysis alone." *

The Pasteur filter acts simply as a very fine strainer, and is capable only of removing impurities in suspension in the water, impurities in solution being wholly unaffected by it. If the water upon which the filter acts is already chemically pure, and it is desired to remove organic matter in suspension, such as animal and vegetable organisms, clay silt, etc., then the filter can be relied upon to restrain these in passing through the tube. The popular idea, shared by many physicians, that the Pasteur filter is a safeguard against all manner of impurities in water is a fallacy. A sewage-polluted water may be as dangerous to health after it has been run through a Pasteur filter as it was before.

To satisfy himself upon this question, the writer has run through Pasteur filter tubes solutions of aniline purple, sulphate of quinine, sugar, starch, sulphate of copper and carmine, and has recovered in the filtrate all, or nearly all, of the original weight of the solid in solution. In making this test generally 1 gr. of the solid was dissolved in 200 cu. cm. of distilled water.

Of late years many Pasteur and sand filters have been installed in Cincinnati, and the general belief is established among the people that water from them is deprived of pathogenic properties, and yet the case and death rate from typhoid fever seems to be unaffected by their use. The writer thinks this is due to the fact that the spores or the bacilli of the typhoid germ (if such exist in water in a developed state), as well as any poisons in a solution, pass unchanged through the pores of the tube. The porosity of the Pasteur tube is probably much less than that of any sand filter in use in the city, and any matters not intercepted by a Pasteur tube would pass with less restriction through the bed of sand. The writer does not understand that any claim of nitrification is made for the common continuous sand filter, but that this, like the Pasteur, is expected to act simply as a very fine strainer.

Of course, it is unreasonable to suppose that all typhoid cases in Cincinnati can be traced to the use of water from Pasteur and other filters, but in some cases it can be so traced. A single case wherein filtered water alone was used as a beverage raises a just suspicion of the capacity of the filter to effectually restrain the typhoid bacillus or

* Frankland Water Analysis, 1880.

its spores from passing through the porcelain tube or bed of sand, or raises a doubt of the Eberth bacillus, or any other water bacteria, being the true cause of typhoid; and this suggests that the germ theory of disease, so ably expounded by Pasteur and Koch, is not universally accepted, many still holding to the Leibig theory, namely, "that disease is due to organic matter in process of decay communicating the elements of decomposition."

It is known that a Pasteur filter after it has been in use for some time may permit the passage of bacteria, and it will be necessary at frequent intervals to subject the tubes to a high temperature for the purpose of destroying all organic matter contained in the porous porcelain.*

Dr. Currier has shown that plate cultivations of bacteria can be made from water after it has passed through a Pasteur filter,† indicating that such water is not sterilized. It has been stated that the channels through the Pasteur tube are said by the makers in this country to be about $\frac{1}{25000}$ in., or 1 micron, in diameter, if considered as a round perforation. Now, many bacteria are less in diameter than a micron (Cruikshank), and the spores of all bacteria are much less in diameter than the developed organism. May it not be possible that the smaller bacteria or their spores pass unchanged through the porous Pasteur tube? The writer is aware that this theory is contrary to the common belief that water absolutely sterile and fit for bacteriological purposes is obtained by this mode of filtration, but the question is submitted for what it is worth. He feels safe, however, in asserting, from his own observation here in Cincinnati, that if absolutely sterile water is obtained from Pasteur filters, that the cause of typhoid fever cannot be found in the Eberth bacillus, but is due to a specific poison or ptomaine in the water, which the filter is powerless to remove.

From experiments by Drs. Frankland and Tidy‡ on the sewage of London and other English cities, the organic matter in solution will range from an equal amount to twice the quantity in suspension. Experiments by Mr. Dibden on London sewage show the ratio of dissolved to suspended matter to be as 1.00 to 0.77, or, of the organic matter in sewage, the larger part is in solution and wholly beyond the influence of any filter which acts simply as a strainer.

* Sternberg, "Manual of Bacteriology," 1893.

Trans. Am. Soc. C. E., Vol. xxiv.

‡ Tidy, "Treatment of Sewage," 1887.

The only effective filtration is that in which the organic matter in solution, as well as the suspended matter, is removed from the water, and any filter failing to do this cannot be considered a success from a hygienic standpoint.

To determine the character of any water before and after filtration, or of any water about to be adopted for public uses, tests should be made chemically, for the ammonias, chlorines, nitrites and nitrates, for solids and hardness of water, and, if suspected, for mineral poisons, microscopically for the organisms and amorphous matter; and bacteriologically for the bacterial life in the sample of water. If the chemical test fails to develop any dangerous matter in solution, if the test with the microscope shows no low or objectionable organisms and no amorphous matter, and the test for bacteria reveals no pathogenic or parasitic microbes, such water, in the light of present knowledge, is possibly the best for drinking purposes we can hope for.

The city of Cincinnati has been well supplied for several years with mechanical filters, and yet, from statistics gathered by Dr. Stallard, of San Francisco, this city, of six in this country and five in England, stands at the head in mortality from typhoid fever, having a death rate four and a half times as great as that of London, higher than that of Philadelphia, and twice as great as Boston.

Admitting typhoid to be a water-borne disease, then it appears from its prevalence in this city (Cincinnati) that the filters in use here are worthless in combating the cause. In other words, the danger from typhoid seems to be as great after our water has been filtered as before.

The Ohio River, before it reaches Cincinnati, receives the sewage and surface drainage of upwards of 100 cities and towns, many of which have systems of sewers to facilitate the discharge of their sewage into the river or its tributaries. When the stream reaches Cincinnati the dilute sewage is pumped into the reservoirs and served to the people. What is true of the river at Cincinnati is emphasized as we proceed down stream, this city enriching the sewage-laden stream to the extent of 36 000 000 galls. per day, as a dry weather discharge, and, of course, many times that quantity during periods of rainfall, when our street wastes are washed into the sewer and carried into the river.

The water supplied to Cincinnati is not worse than that supplied to some other cities. But negligence or indifference in this respect by

our city does not justify it in any other, and if the same energy that is given to politics by the officials of Cincinnati was applied to the securing of a supply of pure water, there is no doubt that our water quality would be improved, and our alarming death rate from typhoid fever be diminished. Here, at least, and possibly in other cities, politics and water do not mix, and the harvest of our dearest idols goes on without restraint.

While it is not certainly established that typhoid cannot be acquired by other processes than water, milk or food, the weight of evidence now before us is that it is nearly always brought into the system through drinking water.

Considering typhoid as a water-carried disease, and assuming that one who drinks only pure water cannot contract it, then it follows that with pure water universally supplied to consumers, typhoid will no longer exist.

The Massachusetts State Board of Health has made extensive experiments on the filtration of water through beds of sand and loam, with very satisfactory results,* but at such slow rates of filtration (23 to 69 galls. per square foot of sand bed per day) as to discourage the adoption of this method in treating large volumes of water.

A report before the writer of a test of one of the mechanical sand filters shows about the same results in the removal of bacteria at rates of filtration as high as 166 000 000 galls. per acre per day, as the Lawrence experimental filters give at rates of 2 000 000 galls. per acre per day; or, while working at a rate of filtration over 80 times as great, the mechanical filter gives the same efficiency in removal of bacteria.

It is common for physicians in cases of doubt of the purity of a water supply to recommend that water for drinking purposes be boiled, but the boiling of water renders it insipid and unpalatable, and it is claimed by some of the manufacturers of filters that water deprived of certain of its natural gases and solids in solution (as it will be by boiling) is not as wholesome as natural waters. The writer has been unable to obtain any reliable information of the influence on the human system of the harmless salts and gases in solution in natural waters, and is in doubt whether the continuous use of boiled water as a beverage will be deleterious. Considering that filtered and boiled water will be limpid and sterile, and deprived of all toxic properties,

* Twenty-third Annual Report, Mass. State Board of Health.

and assuming that such water will not be injurious to the system, may not the problem of a safe drinking water finally be solved by combined filtration and distillation ? If carried out to its legitimate conclusion, this would mean the treatment of a sufficient quantity of water by the corporation for drinking and culinary purposes, and the delivery of this to consumers through an independent system of comparatively small mains. But the expensive apparatus for distillation, the cost of duplicating the street mains, even with pipes of small diameter, and especially the large annual expense of operation, might at first sight seem to prohibit any attempt by this process to purify water on a large scale.

As this question is sometimes raised in the discussion of quality of water, it may be of advantage to inquire what will be the cost of procuring absolutely pure water by filtration and distillation combined.

Assuming a daily consumption of 1 000 000 galls. of potable water, or 347 100 lbs. per hour, an efficiency of 75% for the evaporating apparatus = 11 250 thermal units per pound of coal, and an average of 1 124 thermal units required per pound of water evaporated, then 1 lb. of coal will distill 10 lbs. of water at atmospheric pressure, and the consumption of coal will be 417 tons (2 000 lbs.) at $2 per ton, or $834 per day.

Estimating 3 lbs. of water evaporated per hour per square foot of heating surface, then to deal with 1 000 000 galls. per day there will be required 115 700 sq. ft. of heating surface, and, allowing 2 000 sq. ft. per boiler, will require 58 boilers. Tubular boilers, 7 ft. diameter, 18 ft. long, will cost, set and trimmed, $1 800 each, or $104 400 for the requisite number. Boiler house to accommodate them, $35 000. Allowing 10 lbs. of steam condensed per square foot of cooling surface in condensers, then 35 surface condensers, with 1 000 sq. ft. of cooling surface to each, at a cost of $52 500, will be required. Two sets of sand filters, each of 1 000 000 galls. daily capacity, will cost $12 000; filter house, $4 000 ; pipes, valves and sundries, about $20 000 ; total, $227,900, or in round numbers, $228 000.

ANNUAL EXPENSE.

Interest on cost at 5%	$11 400 00
Sinking Fund to redeem bonds in 40 years, at 4%.	2 398 56
Fuel, $834 × 365 days	304 410 00
Labor, 45 men at $2 per day, 3 men at $5 per day,	38 325 00
Total, not including repairs	$356 533 56

and the cost of so purifying water will be about $\frac{1}{10}$ of one cent per gallon.

In the items of cost no allowance is made for pumping, because this would be required in any case, whether the water is treated before delivery, or pumped without treatment from the source to the consumer; nor for cooling water for the surface condensers, because the 97 or 98% of untreated water may be made to pass through the condensers as cooling water without extra cost.

This, however, is not the whole cost, for allowance must be made for a duplicate set of mains of small diameter to distribute this water. Estimating 250 miles of mains at an average cost of $4 500 per mile = $1 125 000.

ANNUAL CHARGE.

Interest on cost at 5%	$56 250
Sinking Fund to redeem bonds in 40 years, at 4%	11 835
Total	$68 085

Cost per gallon of water treated, about $\frac{1}{50}$ of one cent, or a total cost of $\frac{12}{100}$ of one cent.

Thus, water absolutely free from all germs and their spores, and free from all toxic properties and matter in suspension, can be obtained, if the work of purification is conducted on a large scale, at the rate of 8 galls. for one cent.

Is absolute immunity from typhoid fever, cholera and all other water-borne diseases worth this expense? The writer thinks it is.

Applying this total annual cost to the city of Cincinnati, with a population of 325 000, then the annual cost for the prevention of typhoid fever in this city, will be about $1 31 per capita. Considering the fact that we had over 400 cases of typhoid in the city from December 12th, 1893, to January 12th, 1894,* it would seem that this annual amount per capita is not great for immunity from this disease. Whatever may be said in this paper with reference to Cincinnati will apply to any other city similarly cursed with a public water supply which may, sooner or later, carry disease and death into every household.

From a communication to the writer by one of the principal manu-

* This statement was made to the writer by one of our leading physicians.

facturers of sand filters in this country upon the method pursued in freeing water of bacteria and dissolved organic matters in the continuous sand filter, he takes the liberty of making the following extract:

"Our method of purifying water is both chemical and mechanical, and consists in first treating the water with a suitable reagent, so as to render the objectionable matters insoluble and coalescent. We then allow five minutes to one-half hour for the coagulation or conglomeration of the precipitated substances, and finally pass the water through a filter bed of white machine-crushed quartz, which much resembles in appearance and size granulated sugar. The filtering beds in our filters average about 2 ft. in depth, through which the treated water is made to pass or percolate. The grains of the filtering material are sharp and easily retain the coagulated substances, whatever they may be, upon and in the interstices of the bed, so that the water after passing through the filtering bed of quartz emerges clear and brilliant and free from whatever objectionable impurities were previously aimed to be removed.

"The proper treatment of the water prior to filtration is as important as filtration itself, for it is evident that a filtering bed composed as above described would be too free and open to arrest only the grossest matters in suspension. A bacterium or spore is, as you know, from $\frac{1}{20000}$ to $\frac{1}{100000}$ in. diameter; while probably the smallest of the interstices in the bed would not be less than $\frac{1}{100}$ in. in breadth. There are, therefore, but two mechanical methods available for retaining these germs. One, which is the method followed by the Pasteur, being to provide crevices or passages through the filtering material a trifle smaller or finer than the smallest bacterium. The other method is to coagulate the bacteria into masses large enough to be retained by larger passages. To effect this coagulation or conglomeration of the bacteria, sulphate of alumina or alum is used. The action of the sulphate of alumina is briefly as follows: When it is added to the water it decomposes the bicarbonates of lime and magnesia always present in waters to a more or less extent, and the products of the double decomposition are sulphate of lime or sulphate of magnesia, and carbonic acid gas and hydrate of alumina. The former two are as soluble as they were originally, and remain in the water; the latter is, however, insoluble, and is precipitated as a white, gelatinous mass, and, being coalescent in itself, envelopes the bacteria which adhere to it, and, therefore, when this precipitate of alumina is filtered out of the water, the bacteria, spores and all the infinitesimal matter in suspension is retained in the precipitate, and the water, therefore, can be easily and rapidly filtered through a filtering bed that would be absolutely worthless if no chemical treatment were used.

"Regarding the dissolved matters would say that these are removed by precipitating them directly, as, for instance, where lime and

magnesia are objectionable, we use sal soda or soda ash or caustic soda to precipitate the lime as carbonate, and this precipitate can be readily filtered out with our filter, therefore depriving the water of its lime and magnesia which was originally in solution, as it is in some of our sparkling artesian waters; as a result, the water is rendered perfectly or practically soft. The dissolved organic matters are almost entirely removed in the same manner by the alumina at the same time the bacteria are removed. We further remove the dissolved organic matters by subjecting the waters to aeration, which consists in forcing air into the water, oxidizing the decomposable organic matter which converts them into nitrites or nitrates, which are inert and harmless. These are the three methods most generally used in the purification of waters, although there are cases where special treatment is required. The average amount of alumina used does not exceed one-fourth of a grain per gallon, which is but 32.55 lbs. per 1 000 000 galls., and costs about $1\frac{5}{8}$ cents per pound."

Apart from a bed of sand common to all such filters and which acts only as a strainer or intercepter of suspended matter, the purification of water by the continuous sand filter appears to depend upon—

First.—The use of alum as a coagulent, to act upon the bacteria and dissolved salts in solution.

Second.—The use of soda ash or other reagent for softening purposes.

Third.—Aeration to oxidize dissolved organic matter and convert these into nitrites and nitrates.

Regarding the use of alum in sand filters much diversity of opinion exists. The manufacturers of these filters recommend it because it produces a clear filtrate while working the filter at a high rate of delivery, but in such uses of the mechanical sand filter as have come under his control, the writer has discouraged the corporations or water companies in the use of alum or any other astringent for precipitating the suspended organic matters, fearing that the excessive use of the coagulent would result in injury to the animal system. He is informed, however, by several of the manufacturers of mechanical sand filters that no harm can result from a surplus of alum, because any excess above that required to precipitate matters in suspension will unite with the mineral bases in solution in the water and produce insoluble or harmless compounds, as sulphate of lime, sulphate of sodium and hydrated alum. Upon the other hand, the excessive use of alum in a sand filter in one of our Cincinnati hotels, several years ago, was believed at the time to have produced among the regular boarders serious

bowel troubles, which were said by physicians in attendance to be due to the action of the astringent in the drinking water on the absorbent vessels of the stomach and intestinal canal. At best, the alum probably acts only on matters in suspension in the water, and has no influence on matters in solution * if these are derived from sewage sources.

The use of sal soda, soda ash or any reagent for softening the water would be demanded from a strictly sanitary standpoint only with those waters of great hardness, since small quantities of lime and magnesia are not generally regarded as injurious to the human system.

If the results of Prof. Drown's experiments on the aeration of natural waters are to be accepted as conclusive upon this point,† then the claim for oxidation of dissolved organic matter and its conversion into nitrites and nitrates is a mistake. No such result will follow the aeration of water containing dissolved organic matter, but, as Prof. Drown shows, aeration may be beneficial in expelling from water objectionable gases in solution; as, for instance, sulphureted hydrogen, but no chemical reaction can be expected from simple aeration.

It will be noticed that the first step in the purification of water described by the writer's correspondent is the treatment with alum, and that the water is at rest for a period of from 5 to 30 minutes, to give time to the alum to act as a coagulent and precipitant. This would seem to indicate an attempt at intermittent filtration with the continuous filter, or would involve the alum treatment of water in settling tanks, somewhat after the style of the precipitating tanks used for the purification of effluent sewage.

A successful filter must remove both suspended and dissolved matter and the toxic properties in water, otherwise it will be of doubtful utility as a sanitary appliance, because the average citizen accepts such devices altogether upon the representation of the manufacturer, under the impression that he has a safeguard against disease from a water source, when in reality he has nothing of the kind, and his danger from water-borne disease may probably be as great after he filters his drinking water as it was before.

According to Prof. Baumeister,‡ we can safely drink a sewage-polluted water when the sewage and water are mixed in certain proportions, depending upon the amount of organic matter in the sewage and

* Parkes' "Practical Hygiene," 1892.

† Twenty-third Annual Report, Mass. State Board of Health.

‡ R. Baumeister, Cleaning and Sewering of Cities, 1891.

of that previously in the water. But he depends altogether on chemistry for the test of potability of the water, when it is well known that chemistry is powerless to reveal infectious properties or bacteria in the water. He states, upon German authority, that water may carry $2\frac{1}{3}$ grains of organic matter to the gallon and still be potable. Looking at the question from a chemical standpoint, this may be true, but from a broad, sanitary standpoint any organic matter in drinking water known to be from a sewage source is unsafe.

The statement by Prof. Baumeister that sewage containing 29.2 grains of organic matter to the gallon may be mixed with river water containing 1.2 grains of organic matter to the gallon in the ratio of 23 galls. of water to 1 gall. of sewage, and the mixture be safe for drinking purposes, seems to me to be very dangerous, because the sewage may contain the germs of typhoid fever, which no amount of dilution can eliminate. Moreover, advice like this, instead of promoting the purity of water supplies and the public health, is calculated to impair both.

It is but fair to state that Prof. Baumeister is looking at the matter solely from the standpoint of sewage disposal into running streams, and it is doubtful if the selfish motive of ridding a community of sewage by generally the easiest and cheapest method should be allowed to prevail when certain disaster to those who may draw their drinking water from the stream below is bound to follow.

In another paragraph Prof. Baumeister says:

"The objection may be raised to these computations" (relating to sewage dilution) "that the limiting amounts of organic matter in potable water was not fixed under a supposition that a part of it was human excrement."

But all sewers receive some human dejecta, and this at times may contain disease germs, and these germs mixing with a so-called potable water are dangerous. Adapting to our purpose the memorable words of Mr. Lincoln, any water likely to be adopted for drinking purposes may be safe to all people at some times; it may be safe to some people at all times, but it may not be safe to all people at all times, and the protection of those who may at some time be susceptible to its deleterious influences should warn us against the use of any drinking water known to contain organic matter from a sewage source.

Without regard to the manner in which we obtain our drinking water, whether, as Mr. Rafter suggests, "from an absolutely uncon-

taminated source," by filtration, or by filtration and distillation combined, it should never be cooled by melting in it natural ice from an unknown source. No objection can be raised to the melting of artificial ice from distilled water in our drinking water; and, when this is not obtainable, natural ice can be safely used only by placing it in a receptacle separate from that containing the water.

Water is an essential to human existence, 90% of the liquid portion of the blood is water, and of the corpuscles or disks in the circulation nearly 70% is water. Of all the many articles of diet upon which we subsist, none is so important to the support of life as water. With all other articles of subsistence we are usually very careful, not only to demand the best, but to insist that they be absolutely safe to take into the human system; with water, however, we drink whatever comes most conveniently to hand, with no inquiry, and seldom a thought, as to its fitness for the purposes to which it is applied in the animal economy; and yet one of the most dangerous diseases, typhoid fever, can be established in the human system through the medium of drinking water. For, even in the few instances of its being traced to the distribution of a polluted milk, it has been shown that the remote cause or origin was in a typhoid-tainted drinking water.

In many States a human life has a fixed legal money value. The law of Ohio places the worth of a man's life at $10 000. If every fatal case of typhoid fever in the United States is multiplied by this amount the product will reach over $350 000 000 a year, a sum equal to one-third of the present National debt. And notwithstanding the appalling misery and loss of valuable lives from this one disease, typhoid fever would be unknown if the plainest and simplest rules of hygiene with reference to our drinking water were universally followed. In simple terms, if the typhoid germ or bacillus, as it is technically called, were excluded from our drinking water, the disease could not be established. While typhoid is not the only water-carried disease, to us it is the most important, if importance is to be measured by geographical extent, continuous presence and annual loss of life by disease. In the foregoing discussion of the quality of drinking water, while other objections may have been raised against the so-called potable water with which we are generally supplied, the main objection is to the possibility of its introducing the typhoid germ into the system.

Nature's process of purifying water is by distillation on a very large

scale. The waters of the lakes, rivers and sea are evaporated, the vapor ascends from the surface of the earth, is condensed in the clouds, and in due time returns to the earth as rainfall. After we have received the water again into our lakes and streams, or in the absorbent soil, we set about to pollute it with our sewage wastes, and, when thoroughly polluted, we drink it. This may be a very coarse way of stating the case, but is it not the fact? Nature attempts to supply us with a water free from dangerous organic matter and toxic properties, but we will not preserve it in this condition.

In regard to past efforts at water purification, and the attempt to build a standard of purity upon the reduced numbers of bacteria in the filtrate, certain facts have been established in connection with bacteria in water. Thus, the number is not a safe index of the quality of water. Well waters containing so few as four bacteria per cubic centimeter have been fatal to the lower animals, while lake water containing as many as 3 000 bacteria per cubic centimeter has produced no ill effects on the lower animals. Upon the other hand the number of bacteria is a fair indication of the amount of dissolved organic matter in water, but the determination of this by chemical tests is more reliable than to infer it from the number of bacteria. Generally, however, the water bacteria bear a close relation in numbers to the amount or proportion of dissolved organic matter.

While many attempts have been made and several well-known methods proposed to differentiate the typhoid bacillus from other bacteria found in water, none of these seems to be reliable, and the only certain test of the pathogenic properties of any suspected bacteria is by inoculation.

The ordinary water bacteria are not regarded as pathogenic, and pathogenic germs in a water sample are held to be adventitious, and not native to the water. This will partly account for the danger from a water containing few bacteria, and for the innocuous properties of some waters containing many bacteria, and emphasizes the belief now gaining ground, that numbers should not be received as an evidence of quality.

The introduction of a few water bacteria into a sample of distilled water may be followed by a large growth of the same species, but these cannot endure for many days, for lack of nourishment. If the water was absolutely sterile, and no organic matter imparted to it from the

atmosphere while introducing the bacteria, then no growth could occur, and in a short time the bacteria introduced would perish for lack of pabulum.

The typhoid bacillus and the cholera spirillum are not indigenous to water. Water is simply the carrier of these germs of disease, but owing to the difficulty of identifying them, especially the typhoid germ, no one can certainly say whether a suspected water contains the germ until inoculation tests have been made; and if pathogenic germs are found, then an expert judgment only can infer the presence of the Eberth bacillus, or some other bacteria having the same properties. However, if in the inoculation experiments simultaneous tests are made from pure cultures of the suspected bacillus and with the Eberth bacillus obtained from the spleen of one dead of typhoid fever, and the symptoms of the animals experimented upon are substantially the same, then it will be safe to declare the suspected water bacteria as the typhoid germ, even though its morphological and biological characteristics may not agree with the Eberth germ. Thus it may be a variety of the Eberth germ, or it may be a distinct germ capable of producing the same effects in the animal system. To illustrate this in a homely way, no one is likely to mistake beer for whiskey or *vice versa*, but both are known to produce intoxication. In like manner, two pathogenic germs may differ in their morphological and biological features enough to appear to be distinct species of bacteria, and at the same time possess similar toxicogenic properties.

It is unfortunate that cities are so unwilling to conduct such investigations of their water supply during epidemics of typhoid as will clearly demonstrate the condition of the drinking water at all times. As an illustration, one city of several is mentioned. During the later part of the year 1892 and early part of 1893 St. Louis was visited by an epidemic of typhoid fever, which increased the annual death rate from this cause 200 per cent. Investigations were made by the city authorities which clearly established the fact that the disease was practically confined to a district almost wholly supplied with water from the city mains; but, excepting this inquiry, which traced the cause to the Mississippi River water, no tests were made of the quality of the water at the time of the epidemic, or to compare it with the river water at other times when there was no epidemic of typhoid. There is no doubt that careful bacteriological tests would have shown the typhoid

bacillus of Dr. Eberth or Dr. Vaughan in greater numbers than usual in the water, or that the toxic properties developed by the germ when taken into the human system were then much more virulent than at other times.

To solve the question of an absolutely safe drinking water, the filtration to clarify the water should be combined with some process of distillation, and we shall have then, not only pure water, but water that looks pure, which is quite an object when you undertake to educate people upon the question of water quality.

As a matter of interest in connection with the subject of water quality and typhoid fever, the writer has compiled the statistics of typhoid from a number of our larger cities for the years 1890–91–92–93, giving the population, cases (when reported), deaths, and deaths per 1 000 of population (see Table A).

A comparison of the statistics in the table furnishes some interesting information. Thus the water drank in New York and Brooklyn seems to have been superior to that furnished to the city of Boston. Comparing Detroit with Buffalo, Cleveland, Chicago and Milwaukee, it appears that, while all depend upon the Great Lakes for their supply, the water drawn from the Detroit River is better than that from intake cribs set in the lakes a few miles from the shore, or at the foot of the lake, as at Buffalo. As a rule, the cities taking their water supply from the large rivers suffer more from typhoid fever that those that depend upon impounded water, like New York and Boston.

In Table B are given the data from epidemics of typhoid in the cities of Lowell, Lawrence and Springfield, Mass.; St. Louis, Mo., and Pittsburgh, Pa. The title and captions of the table fully explain its contents. Assuming the report of cases to be correct, the mortality from this disease, as shown by the column of percentage of fatal cases, is much greater in this country than in cities abroad.

TABLE A.

Typhoid Fever Statistics.

From the principal cities of the United States.—Compiled from Official Reports of Health Departments.

City.	1890.				1891.				1892.				1893.			
	Cases.	Deaths.	Population.	Deaths per 1 000.	Cases.	Deaths.	Population.	Deaths per 1 000.	Cases.	Deaths.	Population.	Deaths per 1 000.	Cases.	Deaths.	Population.	Deaths per 1 000.
Boston	.....	191	437 245	43/100	966	154	461 093	33/100	765	137	474 063	29/100	.....	148	487 397	30/100
New York	1 100	352	1 705 980	21/100	1 342	384	1 765 645	22/100	1 140	400	1 827 396	22/100	1 005	381	1 891 306	20/100
Brooklyn	.....	218	853 945	26/100	.....	174	880 780	20/100	.....	162	962 530	17/100	.....	165	990 891	17/100
Philadelphia	.....	666	1 046 964	64/100	.....	683	1 069 264	64/100	.....	440	1 092 168	40/100	.....	456	1 115 562	41/100
Baltimore	.....	241	434 151	57/100	.....	150	445 853	34/100	.....	193	458 350	42/100	.....	224	473 193	47/100
Washington	.....	208	250 000	83/100	.....	208	250 000	83/100	.....	183	260 000	70/100	.....	187	285 000	66/100
Pittsburgh	.....	.....	.....	.....	1 047	248	247 000	1	1 145	256	255 000	1	2 398	294	264 000	1 11/100
Buffalo	.....	.....	.....	.....	.....	129	255 664	50/100	.....	98	285 000	34/100	.....	112	300 000	37/100
Cleveland	461	182	277 488	66/100	349	155	299 475	52/100	376	167	309 243	54/100	281	153	322 932	47/100
Detroit	.....	41	230 000	18/100	.....	30	230 000	13/100	.....	117	230 000	51/100	.....	140	230 000	61/100
Chicago	.....	1 008	1 100 000	92/100	.....	1 997	1 300 000	1 51/100	.....	1 489	1 400 000	1 6/100	.....	670	1 500 000	45/100
Milwaukee	.....	73	220 000	33/100	166	77	233 333	33/100	196	76	245 000	31/100	382	95	260 000	37/100
St. Louis	.....	155	450 000	31/100	442	139	452 000	30/100	436	172	460 000	37/100	3 624	514	500 000	1 3/100
New Orleans	.....	50	254 000	20/100	.....	59	254 000	23/100	.....	53	254 000	21/100	.....	39	254 000	15/100
San Francisco	.....	176	300 000	59/100	.....	137	330 000	41/100	.....	113	330 000	34/100	.....	106	330 000	32/100
Cincinnati	.....	197	296 000	67/100	270	186	300 000	67/100	245	121	305 000	40/100	214	134	310 000	43/100
Louisville	.....	142	161 000	88/100	.....	130	161 000	81/100	.....	116	161 000	72/100	.....	135	161 000	84/100

TABLE B.

Typhoid Fever.

Statistics Showing Fatality of Epidemics in Lowell, Lawrence and Springfield, Mass., and Annually for Pittsburgh and St. Louis.

Locality.	Date.	Cases	Deaths.	Percentage of fatal cases.
Lowell, Mass	September, 1890	47	10	21
"	October, 1890	95	9	9.5
"	November, 1890	171	29	17
"	December, 1890	159	24	15.1
"	January, 1891	78	17	22
Total and averages		550	89	16.2
Lowell, Mass	November, 1892	19	3	16
"	December, 1892	70	10	14.3
"	January, 1893	38	10	26.3
"	February, 1893	14	7	50
Total and averages		141	30	21.3
Lawrence, Mass	November, 1892	14	4	28.6
" "	December, 1892	32	9	28.1
" "	January, 1893	72	3	4.2
" "	February, 1893	23	12	52
Total and averages		141	28	20
Springfield, Mass	July, August, September, 1892.	155	32	20.6
St. Louis, Mo	April, 1892; March, 1893	3 624	514	14.2
"	August, 1892.	70	11	15.7
"	September, 1892	142	23	16.4
"	October, 1892	261	48	18.5
"	November, 1892	1 923	124	6.4
"	December, 1892	945	205	21.7
"	January, 1893	114	42	36.8
Pittsburgh, Pa	1891	1 047	248	23.7
"	1892	1 145	256	22.4
"	1893	2 398	294	12.3

DISCUSSION.

Desmond FitzGerald, M. Am. Soc. C. E.—A paper on the quality of water supplies needs no apology to this Society when we consider the army of engineers who are engaged in works of construction and improvement connected with the furnishing of pure water to cities and towns. Mr. Hill has well stated in the opening of his paper that, however much other sanitarians may aid the cause of good water, to the engineer must finally come the designing of works for public supplies. If there is one fact more gratifying than another to sanitary engineers, it is that so much attention is now paid to questions connected with the quality of water. It was only a few years ago that the question of quantity was the principal one to which water engineers devoted their studies. Probably few outside of the specialists realize how varied are the questions that enter into this subject of the quality of water.

We have to begin with a large classification of waters, each of which is subject to its own particular kind of troubles, and many of these are so subtle that it requires a lifetime to understand them. But I do not know of a nobler occupation or profession to which a man can devote his life than that of the improvement of water supplies.

It does not seem to me that we depend upon seeing the actual germs of disease in the water with the microscope or by inoculation from water samples in order to satisfy ourselves that they are present. We have had in Massachusetts several epidemics of typhoid fever in cities taking their water from sources infected with the typhoid bacillus where the death rate has immediately declined on cutting off the polluted water. A remarkable case has recently been presented fully by Mr. Mills before the New England Water Works Association in a description of a new filtering plant installed in Lawrence to rid the water of typhoid germs.

I was recently called to a small town containing 1 300 people, in which over 100 inhabitants were down with typhoid of a malignant type, and of these more than 10% died. In a large institution situated in the town with a separate water supply of its own not one person was taken sick with the disease. Happily I had no difficulty in persuading this town to throw away its source of supply and adopt another pure and abundant source close at hand. Under these conditions, there were so many circumstances pointing to the water as the source of infection that it did not require identification of the actual bacillus in the water.

In many cases a great deal of study is given to purifying a water,

when the same amount of study put into the question of preventing the pollutions from getting into it would do more good. During the past ten years we have devoted a great deal of time and money to this end on the Boston Water Works. The sewage from many of the towns has been pumped entirely out of the water-sheds and improved methods of construction have been adopted for the basins and storage reservoirs for the purpose of improving the quality of the water. We are now engaged in studying swamps existing on the water-sheds and providing plans for draining them, and many observations have been made upon the color of the waters coming from swamps and estimates formed of the probable colors after the improvements have been carried out. There is still, however, something to be said in favor of filtration in the case of almost any surface supply, however well guarded at the sources, and I look in the future to see filtration plants in more general use.

As is the case in many other large cities, we obtain our water supply in Boston by collecting and holding back water from streams during the wet months of the year, in order to distribute it during periods of deficiency in the flow or of long periods of drought. We have, of course, designed our storage so as to cover the longest drought in the past, of which we have a record, and we have made our storage sufficient to carry us through that drought; but it has been strongly impressed upon my mind recently that this is not sufficient to provide a uniform quality of good water. In order that this may be accomplished we must have a much larger amount of storage.

As is well known, surface water improves in quality when kept for a long time in thoroughly constructed basins which are free from organic matter. Now, when water is drawn out from these storage reservoirs at the end of the period of drought and the streams begin to resume a larger flow, then the city has to be supplied with water which has not had the advantage of long periods of storage. From this cause it is not possible always to distribute water of a uniform quality, unless a large surplus of storage is supplied, and it seems to me important that where a city or town is provided with water by means of equalizing the supply of a stream or by drawing from a natural lake, it is necessary that a very much larger amount of storage should be provided than that necessary simply to carry the town or city through the drought.

If the reports of the Boston Water Supply Department for the past few years are examined, it will be found that the number of organisms existing monthly at the surface, in the middle, and at the bottom of all our lakes and storage and distributing reservoirs are published in tables, and that the colors of these same waters and their temperature are given. These monthly averages are made up from weekly examinations. It will also be found that we have a well-equipped laboratory

devoted to microscopic work, and that we have a considerable filtration plant for the purpose of experimenting upon different methods of filtration. In fact, we spend from $12 000 to $15 000 a year upon experiments and analyses connected with questions affecting the purity of the water. This work has naturally revealed many facts of which we were not before aware. There may be some who think that money invested in this way is thrown away; but I think we may very well leave the future to decide this question. We feel, in Boston, that we have made a good investment in this work.

It seems to me questionable whether Mr. Hill's figures for the cost of separating the drinking water from the rest of a supply are sufficiently large. It has not been considered that we can accomplish this result in Boston with so small an expenditure per gallon.

Aeration has been referred to in this paper. It has been found on the Boston Water Works that no amount of aeration will affect the quality of the water, although we have more organic matter in the water than I should like to see. The truth is that the water contains sufficient oxygen in its natural condition, so that the addition of any more has no effect whatever. On the other hand it is true that there are many waters which are so deficient in oxygen and in which the organic matter is in such a condition that aeration produces wonderful effects in a very short time.

It does not seem possible to provide general rules which will apply to all waters. However much we do not know, there is one thing of which we feel sufficiently certain, and that is as to what good water really is; and this is the goal upon which we should keep our eyes and the standard to which we should work.

Charles Francis, M. Am. Soc. C. E.—What may be called the germ of the typhoid bacillus may be generally found in the larger intestines of healthy people. These germs being introduced into the upper or smaller intestines through the medium of drinking water and finding there suitable pabulum, develop into the true typhoid bacillus.

William E. Worthen, Past President Am. Soc. C. E.—As engineer in charge I have just completed a small water works at Southampton, L. I., in which the principle has been adopted of not exposing the water from the driven wells to the light till it is drawn by the takers. From the wells the water passes through the pumps into air-tight receivers or tanks of steel 6 ft. 6 ins. diameter and about 50 ft. long. There are three tanks which are filled at the maximum pressure of nearly 100 lbs. One of these receivers is open always to the village service; the other two are closed under the 100-lb. pressure. When the pressure in the first receiver falls to nearly 40 lbs., one of the reserved tanks is opened to raise the pressure in the mains and after another fall the third tank is opened. For fire purposes the tanks can be opened and adequate pressure secured promptly.

The water is strongly aerated by the compressors, which maintain the air pressure and volume, and the water is cool for domestic use. I am anxious to see its sanitary effects, as it will probably prevent the development of *confervæ*, and shall look to the report on vital statistics. With regard to the growth of microscopic organisms, I do not know of any standard authority, but think that sterilization should be used carefully, that "numerous bacteria exist in the digestive canal of a man in good health, and that they are not only innoxious, but they play an active part in gastric digestion and especially in the transmutation of albumens into peptones"; that they are necessary for the support of the white blood corpuscle and consequently of the red. My suggestion would be, sustain your own phagocyte and look to the effects as they can be seen naturally rather than to the present results of microscopic observation. It takes something more than microbes to produce ptomaines, there is a necessity of some pabulum and condition, and good health must depend largely on the surroundings and habits.

Charles H. Snow, Assoc. M. Am. Soc. C. E. (by letter).—Mr. FitzGerald has spoken of typhoid fever in a small town where those not using the common water supply were totally exempt from the disease. Such instances are common and furnish the most forcible argument for good water kept good. An interesting incident of the same kind was afforded by a small town in which I was located for some time.

The town was upon the sides of, and in the valley between, two hills. It had two sources of water supply. Mine water pumped from about 500 ft. below the surface, and surface water collected in wells. The mine water was freely given to all who sent for it, and those using it were not confined to any particular district, but were more or less scattered throughout the entire town. A miner having contracted typhoid fever elsewhere sickened upon one of the hill slopes, whence the fever presently spread over the entire population of 4 000 to 5 000 people. In one house sixteen cases developed. There were no instances of fever among those using mine water. As an illustration of the ignorance frequently displayed respecting water, while the fever was prevalent wells sealed by the Local Health Board were broken into by families insisting on the use of their own supply. I also recall seeing people dipping water from a small brook running through the town, which was practically a sewer, that a trip to the mine for water might be saved.

As the province of the physician is to cure disease, so that of the engineer is to prevent it, and a more pronounced method of popular instruction would be found useful in accomplishing this result, and might come within his province.

S. Whinery, M. Am. Soc. C. E. (by letter).—Mr. Hill has given the Society a very valuable paper upon the subject of which he treats. While he does not claim that there is much in it that is new, he pre-

sents a valuable summation of the present state of knowledge on the subject, and some pertinent suggestions as to the sanitary defects in present methods of water supply, and the means that are available for securing pure drinking water, and of avoiding its contamination before and after being collected or stored for use. From the evidence now in our possession, the problem of securing an uncontaminated supply of water for domestic use, is not only not yet practically solved, but is every day becoming more difficult of satisfactory solution. Unless collecting grounds are fully controlled, and carefully watched and guarded, there can be no certainty that uncontaminated water will be secured. As the population of the country increases and land becomes more valuable, it will become more difficult and expensive to secure control of collecting grounds, and to guard the supply against contamination. Even under the most favorable conditions, the danger of pollution will be very considerable.

The evidence is accumulating that we cannot rely on artificial filtration to remove from drinking water the germs and their spores that cause specific diseases. It was for a time supposed that filters of the Pasteur type could be depended upon to entirely remove deleterious elements from water, however polluted. It is now conclusively proven that in this we were but leaning on a broken reed. Combined filtration and oxidation by the use of filtering beds of sand and coarser materials has given great promise of success, as recently conducted in a painstaking and scientific manner under the careful supervision of competent experts and engineers. What the result would be under ordinary conditions of practice is at least problematic. The possibilities of lack of intelligence, carelessness, and management under engineers or superintendents more noted as ward politicians than as civil engineers or sanitary experts, are not pleasant to contemplate. Probably very few of us, in the present state of knowledge on the subject, would be willing to trust the health, and possibly the lives, of ourselves and our families to the use of drinking water known to be, in its natural condition, polluted and dangerous, if the only safeguard was purification by this method, under such management as too frequently controls the water supply of our cities.

The possibility of securing a perfectly safe water supply from deep wells in or near a great many of our cities, especially those situated within the glaciated regions of the country, is worthy, I believe, of far more attention than has been given it in this country. The evidence is accumulating of the existence of a great number of considerable streams of water flowing in the beds of pre-glacial streams, through beds of sand and detritus, so far below the present surface that the water has been subjected to the most perfect filtration, so that it is pure and wholesome beyond question. Such water supplies are often, though not so frequently, found in regions outside of those subjected

to glacial action. The possibility of securing such supplies should be thoroughly investigated in the vicinity of every city where there is any doubt about the purity of the supply of surface water. To this end, the discovering and mapping out of pre-glacial water-courses should receive more attention than it has heretofore, over the whole region of glacial action.

To me, the most important and suggestive part of Mr. Hill's paper is that relating to the purifying of water by boiling and distillation. This is not, of course, a new idea, but it is recalled to the attention of engineers by Mr. Hill at a most opportune time. Distillation is Nature's own method of water purification. Our standard of purity of potable waters is, and will continue to be, water distilled by the heat of the sun and condensed from the clouds by Nature's processes. The cup of water we collect as it falls from the clouds is, barring the slight possibility of contamination by germs and impurities floating in the air, absolutely pure and wholesome for domestic use. No matter how impure it may have been before its distillation, it may now be used with perfect safety. It is possible that a portion of it may have come from the filthiest cesspools, another portion from the excrement from fever hospitals or the waste from diphtheria wards, and still another portion may have come from the filthy haunts of cholera patients in the far East, yet we may now drink it with impunity.

Distillation is the one method of water purification that all are agreed is perfectly effective and reliable.

The only question about the practicability of this method is that relating to cost. Mr. Hill has treated of this part of the subject with considerable detail, and has shown that a supply of absolutely pure water for domestic purposes can be secured at a cost, which, considering the great benefit that would result, is certainly worth incurring. I believe, however, that the cost may be materially reduced below Mr. Hill's estimate. It will be noticed that he contemplates condensing and cooling the distilled water by surface condensers cooled by the 97 or 98% of water that must be provided for purposes other than drinking. This would mean the wastage of all the heat given up in the condensation and cooling of the distilled water. If, instead of thus wasting this heat, it be utilized for heating the water to be distilled, the process would be cheapened to that extent. This might be readily accomplished by passing the steam to be condensed and the hot condensed water through pipes surrounded by the incoming water on its way to the boilers. Just how much of the original heat could thus be returned to the boilers, I am not prepared to say; but it is, I think, safe to say that 40% of it could be thus saved and re-utilized. Assuming that this is possible, it would not only reduce in the same ratio the cost of fuel and attendance, but the cost of the plant for distillation also. Making

such modifications as this assumption will allow, and making some other changes in Mr. Hill's estimate as seem warranted, we shall have the following as the cost of treating 1 000 000 galls. per day:

Cost of plant for distillation....	$135 000
Cost of separate system of pipes for a city of 160 000 population.....	450 000
Cost of plant for aeration of water if thought necessary.....	15 000
Total.....	$600 000

Cost of Operating for one Year.

Interest on investment at 4 per cent.....	$24 000
Repairs and renewals at 5 per cent.....	30 000
Cost of fuel.....	91 500
Cost of labor and superintendence.....	24 000
Total.....	$169 500

which, divided by 365 000 000 galls., gives as the cost of purification per 1 000 000 galls, about $465.

I have no data at hand as to what amount of water would be necessary for drinking and such other domestic purposes as would insure freedom from specific diseases caused by contaminated water, but I think it would be safe to assume that the amount would not exceed 6 galls. per capita. On this assumption 1 000 000 galls. would be sufficient for a city having a population of 160 000, and the cost per capita per day would be less than three-tenths of 1 cent, and the cost for a family of five persons would be 1½ cents per day, or about $5 50 per year.

It is to be anticipated that the most serious difficulty in operating such a system will be found in the proper regulation of the use of the purified water. On the one hand, some families would be disposed to use the pure water for other than the purposes for which it is intended, and others, either from carelessness or to avoid the cost, would be likely to omit its use. The first difficulty might be met by the use of meters at every house, and for the use of such meters a reasonable rental would have to be charged.

The opposite difficulty could, perhaps, be best met by requiring by municipal ordinance the use of the pure water for certain stipulated purposes, and making it the duty of sanitary inspectors to see that the ordinance was complied with.

What I have said is intended only as an outline of what might be done in this way toward the furnishing of an absolutely pure supply of water for domestic use. The subject is of such great importance as to merit, in my opinion, the most careful consideration and investigation of the system suggested, by water-works' experts and sanitary engineers.

William P. Mason, Esq. (by letter).—The author of this paper appears to be a believer in the power of water to spread disease, but some of the statements and quotations advanced by him would certainly go far to unsettle the public mind and cause lack of faith in the teachings of some able masters.

He says: "While water is held to be a carrier of disease germs, the writer is not aware that any investigator has ever claimed to have seen these germs in water, even under the highest powers of the microscope; and the evidence that water is such a carrier of pathogenic bacteria is obtained by inoculation from water samples of nutrient media in test tubes or on culture plates."

"The typhoid bacillus in water has never been seen with the microscope without previous cultivation of the germ in nutrient media. Nor has it ever been demonstrated, so far as the writer is aware, that the presence of bacilli in water can be proven, excepting by delicate and difficult bacteriological processes."

That single individuals of the Eberth bacillus should escape direct detection is hardly to be considered surprising, in view of the enormous volumes of water in which they are suspended. However difficult the processes of modern bacteriology may be for a tyro, it is hardly just to consider them unreliable in the hands of such experts as Koch, Pasteur or Eberth; and, if any one of these men, or of many others who might be named, should state that he had secured pure cultures of a specific germ under circumstances which excluded the possibility of extraneous contamination, we should be exceedingly liable to believe him.

Again: "It is well understood that the infective element of typhoid fever can be present in water and the chemical test be powerless to disclose it."

True enough, but it does not complete the story. During an investigation following a serious outbreak of typhoid fever in the Tees valley, England, the medical officer of the Local Government Board, London, caused preparation to be made of samples of pure water to which small quantities (50 and 25 parts per 1 000 000) of typhoid dejecta had been added, and these samples were then submitted to prominent water analysts for examination. No results upon which an adverse report could be based were obtained. The contaminated waters were pronounced pure. It must be remembered that the polluting material, as weighed, being very largely water, the pollution appeared greater than it really was. Fifty parts per 1 000 000 of the typhoid dejecta corresponded to only 4 parts per 1 000 000 of total dry residue. As a natural

result of these experiments, the purely chemical methods of water examination received very severe criticism, and the advocates of the exclusively bacteriological processes were correspondingly elated, for here were known instances of fatal contamination which the chemists had failed to diagnose. Let this, however, be said in defence. In cases as they occur in practice a serious addition of typhoid dejecta has much that is associated with it of a comparatively inoffensive character, but which reacts with the chemical reagents and tells the tale of sewage contamination, although the analyst cannot venture to state the exact nature of the source from which the pollution is derived.

Not long since the writer claimed that the river water furnishing a large eastern city was contaminated with up-stream sewage, the opinion having been based, not alone upon an analysis of the water at the intake, for the river was large and the consequent dilution great, but upon the difference between that analysis and one of the water taken from above the sewage inflow. The difference was small, but it was noticeable, and there was no other sufficient explanation of its existence than the one given. Later on typhoid fever broke out in the upper valley, and epidemics developed not only in the city in question, but in all the neighboring towns using the river water for supply. Closely related cities and towns, which received their water from other sources, were not affected. Space does not permit of giving details, showing how clearly the case stood against the river water, but it is interesting to note that typhoid germs were most carefully sought for and were not found. That they were nevertheless present, there can be but little doubt. Chemical analysis in this instance did certainly not detect the presence of typhoid, but what it did do was to warn the people, months before the typhoid appeared, that they were drinking diluted sewage, and that they must beware of the time when that sewage should come from pathogenic sources.

The paper in question goes on to say :

"The popular impression that the Koch, or Finkler and Prior, comma bacillus is the cause of cholera is fallacious, or, at least, not proven. The same remark applies to the typhoid bacillus of Eberth. The proof is still wanting that this will cause typhoid."

This last is a quotation from Sternberg's "Manual of Bacteriology," but it is very misleading because it is incomplete.

What Sternberg really says is this:

"Recent researches support the view that the bacillus described by Eberth in 1880 bears an etiological relation to typhoid fever; and pathologists are disposed to accept this bacillus as the veritable germ of typhoid fever, notwithstanding the fact that the final proof that such is the case is still wanting.

"This final proof would consist in the production in man or in one of the lower animals of the specific morbid phenomena which characterize the disease in question, by the introduction of pure cultures of the

bacillus into the body of a healthy individual. Evidently it is impracticable to make the test upon man, and thus far we have no satisfactory evidence that any one of the lower animals is subject to the disease as it manifests itself in man."

Now, that is a very different statement, and conveys a meaning greatly unlike the one suggested by the partial quotation referred to.

The paper again says :

"Absolutely healthy persons have been known to reject the Eberth bacillus in their excrement, showing such, probably, to be in the intestines at all times."

This is an error. The *bacillus coli communis*, which closely resembles the typhoid bacillus, is constantly present in the intestines of healthy persons, and may lead to confusion, but no position such as the above quotation indicates is now occupied by bacteriologists. In this connection Sternberg (an authority frequently quoted in the the paper) says : "No competent bacteriologist, so far as I know, has claimed to find the Eberth bacillus in the fæces of healthy individuals."

As to the doubt thrown upon the correctness of the view that Koch's comma bacillus is the cause of cholera, the work of Sternberg will hardly endorse it. In this connection Sternberg says:

"The etiological relation of this spirillum to Asiatic cholera is now generally admitted by bacteriologists." And also : "The most satisfactory evidence that this spirillum is able to produce cholera in man is afforded by an accidental infection which occurred in Berlin in the case of a young man who was one of the attendants at the Imperial Board of Health when cholera cultures were being made for the instruction of students."

As to the statement in the paper that "fatal cases of typhoid have been attended with none of the Eberth bacillus in the fæces, or in the intestines, the seat of the disease," it is to be noted that Gaffky's investigations show it to be by no means a serious objection. He considers the technical difficulties surrounding a hunt for the bacillus, in some few instances, so considerable as to readily account for a small percentage of negative results; and he cites instances where he found the "germ" after an amount of patient search which extended far beyond the point where the average observer would have ceased work and placed a negative report upon record.

Finally the paper has much to say upon the imperfections of modern filters and the danger of using water therefrom. It goes without saying that pure water is better than purified water, but then the former is often unattainable and we have to do with the latter or go without.

Especial stress is laid upon the fact that even when the filtration is so successfully accomplished as to leave in the filtrate only one or two bacteria per cubic centimeter, yet "a person may imbibe from 250 to 500 bacteria in drinking a single glass of water, some of which may be

pathogenic and produce typhoid fever or some less dangerous disease." Such a degree of excellence in filtration as the obtaining of a filtrate with only one or two bacteria per cubic centimeter is, indeed, rarely attained; yet the public have a right to look with confidence upon a plant which does not pretend to accomplish half that amount of purification.

Consider for a moment what the Altona filters did for that city during the Hamburg cholera epidemic of 1892. The Altona water was taken from the Elbe River at a point below the outfalls of sewers carrying the cholera-infected sewage of 800 000 people. Yet Altona had no cholera (except imported cases), while Hamburg was scourged by it. The cities are practically one, a stranger being unable to tell the dividing line.

Take the numbers showing the efficiency of the Altona filters during one month of 1892.

The bacteria in the raw Elbe water per cubic centimeter varied from 9 370 to 44 140, with an average of 28 667. The average number in the filtered water was 90. This meant a removal of 99.69% of germs of all kinds, 0.31% still remaining. The filtrate was by no means sterilized, but the city was protected from a cholera epidemic under circumstances trying in the extreme. As to the efficiency of sand filtration for water purification, the following figures are given for results found at the Lawrence experiment station, the filters having been operated with water containing known quantities of bacteria:

Rate in gallons per acre daily.	Kind of bacteria added.	Per cent. removed.
1 500 000	B typhi. abdom.	99.93
3 000 000	B. prodigiosus.	99.95

This reduction of the number of germs in a given volume of water is possibly equivalent to a dilution of the unfiltered water with a very large volume of a pure supply, and in this connection the writer of the paper says: "Dilution may reduce the chances of any single individual imbibing a fatal germ, but the germ itself will be just as dangerous when it is imbibed."

This is, doubtless, true, if the individual be especially susceptible, for it has been experimentally shown that a single germ may produce fatal results when injected into an animal very prone to the special disease, but as it has been also shown that when the animal is not very susceptible, the "dose" of bacteria has to be enormously increased to produce any result. We incline to believe that some similar reason may account for the apparent immunity of that fraction of a community which has been equally exposed, but which escapes contagion.

What the paper says regarding the unsatisfactory results observed

where household filters are in use is unfortunately very true, but the fault is more commonly with the attendant than with the filter. The common belief is that a filter, once established, is good for all time, and I could tell tales of what I have seen in otherwise well-organized establishments that would stagger belief. I do not approve of general household filtration, as I believe purification can be better and more cheaply done on the large scale by the municipal authorities, but I cannot think that the Pasteur filter should be swept aside like the worthless contrivance the paper calls it. My experience is that, with proper care, it is efficient. Extended tests were made with it for the Connecticut Board of Health in 1892, which show that it may be depended upon, if the porcelain cylinder be cleaned and sterilized once a week.

Freundenreich has obtained similar results, and has also shown that the length of time during which the filter is efficient depends upon the temperature.

John W. Hill, M. Am. Soc. C. E. (by letter).—The one grand proposition in connection with the quality of water supplies is that a polluted water is the immediate or original cause of typhoid fever and the typhoid symptoms in typhoid malarial fever, and that a water at all times wholly free from the typhoid bacillus can never produce typhoid when used as a beverage, nor in any other way.

Such water is very difficult to find in Nature, or, being found, it is difficult to preserve it free from contamination.

Water gathered at great elevations above habitations and the operations of husbandry, and impounded in large deep reservoirs, is perhaps the nearest approach to sterilized water in Nature which we can hope to make.

Rivers which receive sewage at any point above or at short distances below water-works intakes can never be regarded as safe sources for drinking water. The same statement applies, but generally with less force (excepting Lake Michigan at Chicago), to lakes which are the outfalls for town sewage.

Sand filtration abroad has generally been attended with good results, but it cannot be relied upon to remove all disease germs, and in this country, from my own experience, the continuous sand filter as usually operated is not to be depended upon as a safeguard against disease germs in water. From some investigations which I am now making of the water of the Passaic River, N. J., I find enormous growths of bacteria on gelatine and agar plates, even after the water has been passed through one of our celebrated mechanical filters. Plates being inoculated simultaneously from unfiltered and filtered water, the relative growths of bacteria from the filtered water is very startling. The results of the investigations mentioned above when completed will be published in due time in one of the engineering journals.

In replying to the criticisms of Professor Mason, the writer believes

that water is the carrier of the typhoid and other disease germs, and he is willing to accept the present evidence as proof of this. There is no desire to "unsettle the public mind and cause lack of faith in the teachings of some able masters," and if there is anything in the paper which rejects the conclusions of Eberth, Koch and other investigators of the typhoid bacillus, the writer must confess to such a degree of obtuseness as not to be able to recognize it. If the writer has not made his position clear upon this question in the paragraph at the bottom of page 135 *et seq.*, then the fault lies in the choice of language and not in intention.

In stating that the proof is still wanting that the Eberth bacillus will cause typhoid, the reference was made to Dr. Sternberg's excellent "Manual of Bacteriology," where those who may be interested in this phase of the water question can examine the authority at their convenience and draw their own conclusions.

It might have been better to quote at length from Dr. Sternberg's work, but it was not considered necessary, and would not have changed the substantial fact that "the proof is still wanting" that the Eberth bacillus will cause typhoid in man, however confident Dr. Sternberg, Prof. Mason, and others may be that it will. In this opinion the writer shares, but until inoculation experiments have been made upon man (and this is obviously impossible in an enlightened and humane age), there will remain some foundation for the opinion so often expressed of the fallibility of the germ theory of disease. While the evidence clearly shows the connection of the typhoid bacillus of Eberth with the typhoid fever symptoms, and probably shows it as the cause of typhoid, the positive evidence can be had only in the manner pointed out.

That the processes for the differentiation of the typhoid bacillus from other water bacteria are both "difficult and delicate," even in the hands of a master, Professor Mason is referred to Dr. Vaughan's "Bacteriological Study of Drinking Water," 1892, and to Dr. Sternberg's "Manual of Bacteriology," page 349, last paragraph, as well as to his own paper on "Some Cases of Drinking Water and Disease," 1891, when, notwithstanding his careful attempts at cultivation of the typhoid bacillus from the infected waters of the Mohawk and Hudson rivers, he failed entirely to find the germ. There is no doubt of the typhoid bacillus being in the water at the time of its examination by Professor Mason, but his attempts to show the existence of it were entirely negative. He gives a satisfactory reason for this, but his reason only proves that an attempt to demonstrate the existence of the germ in water is very difficult, and he is undoubtedly aware of the fact that the tests for the germ are very delicate and not very reliable.

The paragraph quoted by Mr. Mason on page 165 was, upon the

advice of Dr. Sternberg, withdrawn before the paper was read at the Convention, and the following paragraph was substituted:

"In order to approach the question of water pollution properly, it must be borne in mind that while polluted water is held to be the cause of certain diseases, exactly how it acts on the human system is not well known. Bacteriologists generally regard the Koch cholera bacillus and the Eberth typhoid bacillus as the causes of these diseases, but this view is not shared by all physicians as it should be if the proof of cause was sufficient; although common prudence should decide us in rejecting any water known to contain the cholera or typhoid bacilli, whether these germs be regarded as the cause or result of disease, since they indicate the presence of the cause even if not themselves the cause."

In regard to the remarks upon the incompetency of any known method of filtration to prevent typhoid fever, the writer can only add to what he has already stated in discussing this aspect of the quality of water, that while filtration may mitigate, it cannot be depended upon to wholly remove the evils of a polluted water. Thus the removal by filtration of 99% of the bacteria is accompanied by a reduction of 75% in the typhoid fever death rate, showing that the 1% of bacteria remaining in the water are as virulent in a pathogenic sense as 33% of the bacteria removed. Professor Mason has stated* that during the epidemic of typhoid fever in Albany and vicinity (1890-91) "boiling of water for drinking purposes was recommended, and no typhoid developed among families who followed the recommendation," clearly indicating that absolute safety from a water of known pollution lay in the direction of sterilization and not in the direction of filtration. This, in short, is the writer's position with reference to the problem of eliminating typhoid fever from the list of diseases by which we are now confronted. Let all polluted water be properly sterilized and there will be no typhoid among the people who drink and cook exclusively with such water.

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* "Notes on Some Cases of Drinking Water and Disease." Professor William P. Mason, 1891.

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TEQUIXQUIAC TUNNEL, VALLEY OF MEXICO.

By ALBERT JOHNSTONE CAMPBELL and FREDERICK WILLIAM ABBOT, Assoc. M. Am. Soc. C. E.; A. M. Inst. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

General History and Description of the Work.—Ever since Cortes established the present city of Mexico on the site of the ancient Aztec Venice, the problem of the drainage of the Valley of Mexico may be said to have occupied the attention of its inhabitants. Numerous have been the projects for dealing with the difficulty, and very large amounts of money have been spent and much work done since the time referred to, work which in some cases has been partially successful or which at any rate has tended (aided by the changes in the rainfall of the district, contraction of the area of the lakes, etc.) to modify considerably the old conditions and to simplify somewhat the problem. It would take too long to enter into this past history in proper detail.

In modern times and during the Empire of Maximilian the project now in course of execution was commenced, and several of the shafts on the line of the existing tunnel sunk to a considerable depth, and machinery and expensive buildings in connection with the work erected. The fall of the empire and the years of trouble for the country that followed, put a complete stop to the works, and it was not until 1885,

when a special Commission or Drainage Board was formed by General Diaz, that work under the direction of Mr. Espinosa, the Government Engineer, was again commenced with any vigor. Want of funds however, prevented any great progress being made until March, 1888, when arrangements for a loan were completed and the work taken in hand by the present contractors, Messrs. Read & Campbell. On the transfer of the work by the Government, the contractors found 1 639 yds. of tunnel completed at the northern or open end and an aggregate depth sunk in the various shafts of some 2 937 ft., four of the shafts being down to tunnel level in the completed section, the remainder, as was proved later, having reached the level at which water was to be encountered in large quantities. The original time allowed for the completion of the work was extremely short and gave rise to the attempt to work from all the shafts at once with a pumping installation at each, as well as from the open end. The quantity of water had, however, been completely underestimated owing to the impossibility, from the nature of the ground, of obtaining reliable data, and this plan of working had to be given up, as also an attempt to prolong the tunnel some 4 miles at the southern end with a view to replacing the canal section, where the depth of excavation exceeded 60 ft. At one time the quantity of water, being raised in several of the shafts, amounted to 1 000 galls. per minute, and the enormous expense was entirely out of proportion to the advance made.

After a number of modifications of the contract the contractors notified the Government that they could not continue at the prices agreed on, nor on the conditions as to time, and finally in March, 1892, an arrangement was entered into by which the contractors continued to carry on the work on behalf of the Government as managers and administrators.

The small size of the shafts, the shape of the tunnel and the character of the ground had all been obstacles to the carrying out of the work in the three years as originally proposed, coupled with the loss of time due to the wrecking of a steamer off Vera Cruz carrying the heavy pumping machinery for the deeper shafts. As regards the shafts it may be mentioned that they were designed 7 ft. by 10 ft. inside dimensions, with an 18-in. lining of brickwork, and, at the time of the turning over of the work to the contractors, were mostly sunk more than half of the total depth required, but temporarily abandoned.

On the section of 6¼ miles of tunnel under construction the shafts are 24 in number, being spaced about a quarter of a mile apart with an average depth of some 175 ft., the deepest being 300 ft. and the shallowest 65 ft. deep.

The city of Mexico is situated on the central table-land of the Republic at an elevation of some 7 500 ft. above sea-level and at the extremity of a large flat valley surrounded by mountains, through which there is practically no exit for the water falling in this basin. The city is at present drained into Lake Texcoco, one of the lakes surrounding the city, but there is little fall even in the dry season, and in the wet season the waters frequently back up in the sewers and cause inundations in the streets. Various palliative measures, such as pumping at the outfall of the sewers, etc., have been adopted which have somewhat modified the evils, but nothing but the completion of the tunnel at present under construction, coupled with proper sewering of the city, can ever cure the existing evils and make the valley and the city what they should be, with the delightful climate and situation. The object of the works is therefore two-fold, to control the water in the lakes and in the valley, getting rid of any injurious surplus, and to afford an outlet for the storm waters and sewage of the city proper.

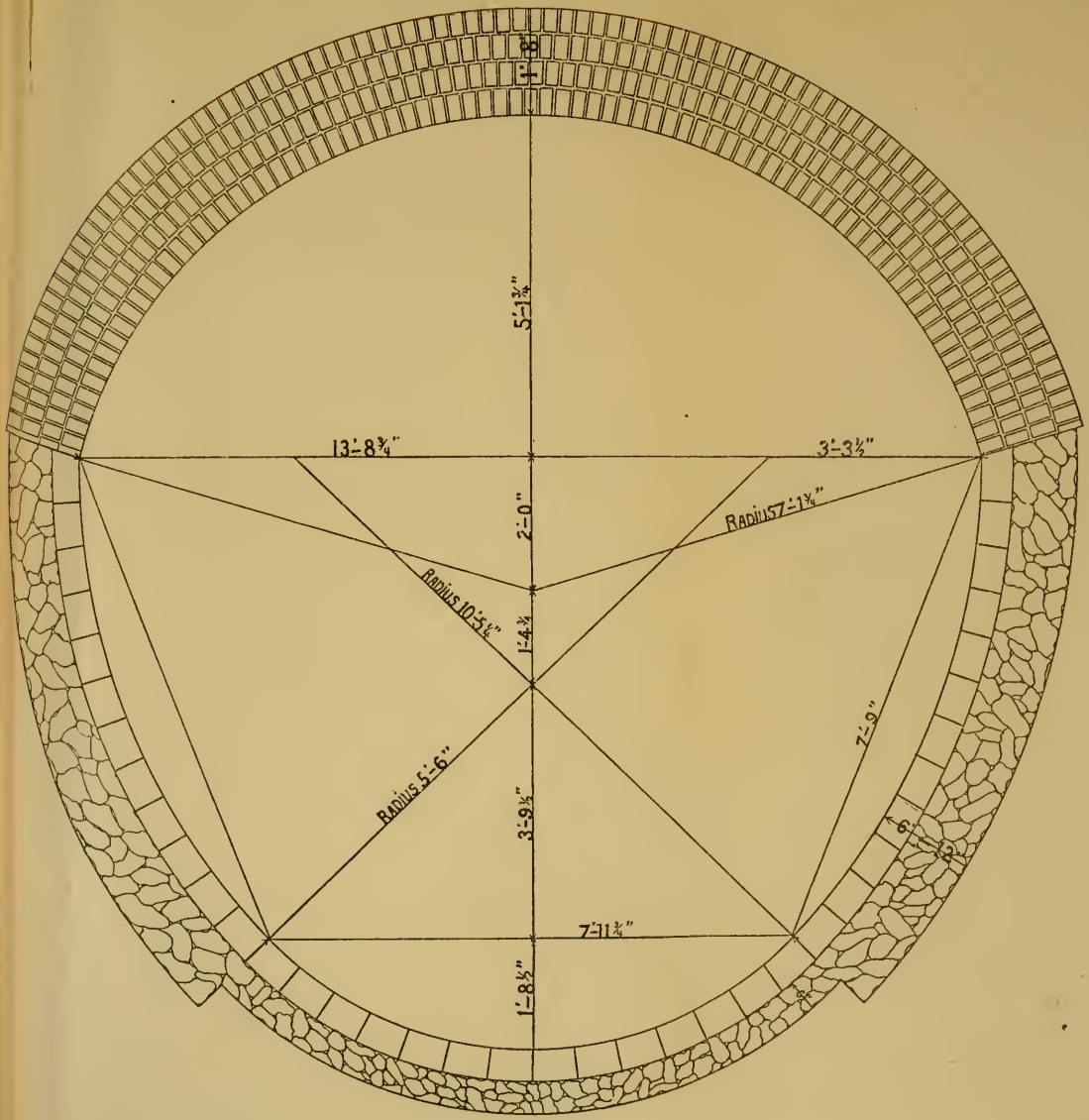
The works consist of a canal some 35 km. long, starting from the city gates, and a tunnel with a length of some 10 km. The canal varies in depth from 5.5 m. to 20.5 m. at the junction with the tunnel.

In March, 1892, the Drainage Commission decided to concentrate, as far as possible, the pumping machinery at the shafts at the northern or open end of the tunnel, and to devote special attention to a vigorous prosecution of the bottom heading with a view to connecting the various shafts as speedily as possible, and of so affording an outlet for the waters through the open end of the tunnel. As time was not such an important element in the contract, and, further, as a great many of the most heavily watered shafts had now, in spite of great difficulties, been sunk and the tunnel in part built from them, this scheme promised to give the best and most economical results. At the date of this change the back of the difficulties had been broken, the tunnel was in active construction at numerous points, and the organization perfect in every respect.

This change in the plan of working was largely due to Mr. J.

Limantour, President of the Drainage Board (now Minister of Finance), who insisted especially on a more vigorous prosecution of the bottom heading at any cost, although at that time the results obtained in driving the heading did not appear likely to reach anything like those ultimately obtained. When this plan was commenced there was about 1½ miles of the tunnel completed at the open end, which afforded an excellent outlet for the water. While the bottom heading was being pushed from one shaft to another, no other work was, as a rule, attempted in the same run of ground, as it was found that it delayed more or less the progress of the heading. As soon as two shafts were connected, tunneling could be commenced at once between them, providing care was taken not to block the water and so stop work in the heading which was being driven ahead to connect with the next shaft to the south. In order to make speedy tunnel progress, it was necessary to obtain as many working faces as possible by the construction of break-ups or intermediate sections of tunnel between the shafts, break-ups having been used by the contractors previously with great success; and so, as soon as a tunnel was started from the two shafts, some convenient spot in the heading between the shafts would be selected and break-ups made through the heading and a length of tunnel opened, by which means two more faces were obtained to work from. The number of these break-ups depended on circumstances, on the nature of ground, etc.; for instance, between Shafts Nos. 14 and 13, one break-up was used; between Nos. 14 and 15, two break-ups, and between Nos. 15 and 16, three break-ups; it was found, however, that two was the best number for convenient working. When the deepest shaft (having a total depth of 300 ft.) was in operation, there were, in working one regular tunnel face towards the north or open end, and one to the south, three break-ups, and then the regular face of Shaft No. 16, north; the faces were divided between the two shafts, and No. 17 had, therefore, to deal with one face to the north and one face to the south, and also a break-up and a half, or three faces, or in all, five faces, a large number for a shaft of such depth, and of such a small section.

By means of these break-ups the progress of the tunnel was very materially increased, as each face would average 60 to 90 ft. per month, making it possible to join the tunnel between two shafts in about three months; where the double-length system (mentioned later) was employed, better progress was made.


5'-1¾"
13'-8¾"
3'-3½"
2'-0"
RADIUS 7'-1¾"
RADIUS 10'-5¼"
1'-4¾"
7'-9"
RADIUS 5'-6"
3'-9½"
7'-11¾"
1'-8½"

Not only was work carried on from the open end and in shafts nearest to it, but also, at isolated points where water could be easily dealt with, both tunnel and heading were vigorously prosecuted.

The choice of points to be worked, and the general scheme of work, the decision as to where heading only was to be driven and no tunnel constructed, etc., were matters of considerable study in order to obtain the best results with the smallest possible expenditure; but it is unnecessary to go into this question here. It suffices to say that the Government placed itself more or less in the hands of the contractors in these matters, and co-operated with them most heartily in all their plans.

It is purposed in this paper to draw attention to the more special points in connection with the construction of this tunnel, not going into the whole detail of construction, as this would lengthen the paper unnecessarily, and only be a repetition of the facts known in connection with other tunnels.

General Description of the Tunnel.—The tunnel section, grades, etc., are those determined by the Government Engineers, under the direction of the Chief Engineer, Mr. Espinosa, as are also the materials employed, etc., the whole work being carried out according to the Government specification.

The tunnel section, as shown on Plate XX, is more or less egg-shaped, but flattened at top and bottom, the chord of the arc being approximately of the same length as the height; the chord is 13 ft. 9 ins., while the height is 14 ft. The flow is calculated to rise as high as the spring of the arch, giving a depth of water of 9 ft. The velocity is calculated at about 4½ ft. per second; discharge about 200 000 galls. per minute, the grade being .72 m. per 1 000 m., or 1 ft. in 1 388.88 ft. The shape of the tunnel is open to a certain amount of criticism, and, as far as the builders were concerned, caused great inconvenience on account of the heavy dish of the invert, increasing the depth of the dead water and greatly cramping operations generally.

The arch consists of four concentric rings of bricks laid with their length horizontal to the arch in the same direction as the axis of the tunnel, and without bond between rings except now and then. The size of the brick is 4⅝ ins. by 9⅝ ins. by 2⅜ ins.; the depth of the arch, 20 ins., allowing for joints. The local tezontle mortar is used in ordinary ground, cement mortar only being used in special cases.

The invert and side walls are constructed of artificial blocks, with a backing of volcanic stone rubble masonry. The thickness of the side walls, including backing, is 18 ins., while the invert or dish has a total thickness of 1 ft. The size of the blocks is 1 ft. 3¾ ins. by 7⅞ ins. by 5⅞ ins., and they are made of 1 part of Portland cement to 3 of sand, rammed in moulds and finished by hand labor.

The mortar with which the side walls and invert are constructed is made of 1 part of lime, 1 part of sand, and 1 part of tezontle.

When cement mortar is used, it is usually made of 1 part of cement to 3 of sand.

Materials used in Construction.—Bricks.—The bricks, made by the contractors on the spot, are required to stand a pressure of about 900 lbs. per square inch.

Blocks.—The blocks used in the invert and side walls are made of 1 part of cement and 3 of sand, as previously mentioned. The cement and sand are first carefully mixed together, usually in a hand rotary machine, and this mixture, after being dampened, is rammed by hand in moulds the size and shape of the block, care being taken that the layers are not too thick, and only sufficient mixture being put in the moulds at each ramming to make a thin layer; iron rammers are used and every effort is used to make the mass as homogeneous as possible. The faces of the block are made to conform to the arc of the side walls and the invert, moulds with templates of the required form being used for the various blocks, while the blocks for the top of the side walls are made with their upper face inclined at an angle equal to that formed by the radius of the arch so as to make an effective key with the arch above.

The blocks, like the bricks, are capable of resisting a pressure of some 900 lbs. to the square inch.

Mortar.—This for the bulk of the work, consists of a mixture of lime, sand and tezontle in equal parts, and only in extraordinary cases is cement used. The lime is of an exceptionally good quality and strongly hydraulic. The limestone is quarried in the immediate neighborhood, and the tezontle, which is a highly ferruginous volcanic tufa; is also obtained close at hand and is ground in the mortar pans to an impalpable powder before being used. The sand is good and clean and fairly sharp. The quicklime weighs about 40 lbs. per cubic foot.

All the mortar is mixed in pans. The lime and sand are first mixed

dry, the tezontle added and the whole then shoveled into the pans and made into mortar. This mortar, when mixed, owing to its being so slow setting, can be allowed to remain some little time before using without injury to its qualities.

Cement Mortar.—This mortar is made of 1 part of Portland cement to 3 of sand, and is usually mixed by hand. It is only used where called for by Government engineers in view of special pressure on arch and side walls. In wet places it was found very hard to prevent the cement mortar from washing away entirely, and an expedient used with fair success, although a questionable method was that of mixing a little clay with the mortar, to give it consistency.

Stone.—The backing is constructed of volcanic or igneous rock found in the neighborhood, laid as rough rubble. This rock is a very hard and heavy class of porphyry, generally with rounded edges, not occurring in pieces larger than 4 cu. ft., and weighing about 160 to 170 lbs. to the cubic foot.

The quantity of materials actually consumed per lineal yard of tunnel is as follows:

1 800 bricks, including packing.

94 blocks.

3 cu. yds. of tezontle and lime mortar.

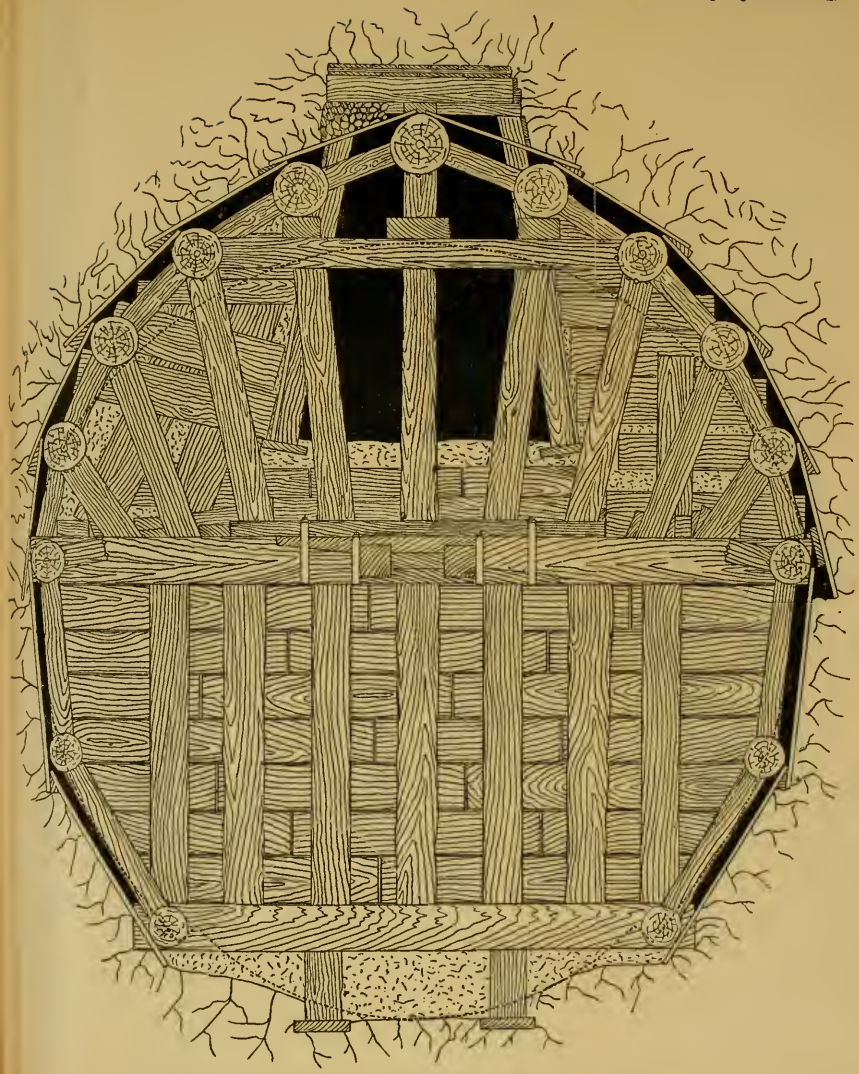
One-fourth barrel of Portland cement.

70 cu. ft. of volcanic stone.

Nature of Ground.—The ground through which the tunnel is driven is of a very unusual character. There are no regular strata, and therefore nothing to depend upon in the way of indications while sinking the shafts in regard to the nature of the ground likely to be encountered. The whole district is of volcanic origin. The hills bordering this portion of the valley of Mexico appear to have been originally formed from materials erupted from adjacent volcanoes, these materials having been deposited under water, probably in great inland salt lakes. Subsequent upheavals have caused the present configuration of the ground and resulted in a confused mass of sand, mud, tepetate of various degrees of hardness, masses of porphyry and some soapstone, with no regularity of stratification. The tepetate, a local name largely used in Mexico, is a term generally applied to a species of sandstone mixed with lime in various proportions. This tepetate takes all forms, from stone of an oolitic character, in which sand and lime

occur in large rounded grains to a stone consisting of a compact mixture of sand and lime with every degree of hardness. In two instances the tepetate proved so hard that it was possible to take out a 24-ft. length without a stick of timber in it. But the amount of ground encountered of this quality has not been more than 1% of the whole. The greater part of the ground met with consisted of a soft but fairly compact material, which, on being exposed to the air, immediately crumbled and swelled, thus throwing, in some instances, very great weight on the timber. Probably 60% of the tunnel ground was composed of this, the rest consisting of sand, compact and running, and sand with boulders, some of it very heavy and some comparatively light ground. The boulders of porphyry were all water worn and rounded, in some cases cemented together by the sand, in other cases quite loose, but always accompanied with large quantities of water. Water was also always met with in large quantities in the hard tepetate and the sandy formations, while the soapstone formations were as a rule comparatively dry. These formations did not succeed each other in regular sequence, but were all mixed up together in a most inexplicable fashion, so that it was impossible to foresee what ground would be encountered from week to week, almost from day to day. In addition to these peculiarities potholes were frequently struck from which water would flow out with great force, bringing dirt, mud and stone, with it. On two or three occasions these bursts of water were so large as to temporarily drown out a pit, and in one case such a tremendous rush of water, mud and stones was encountered in a face 700 ft. from the pit that it tore up 600 ft. of track, twisting up the rails, etc., and filling the tunnel 4 ft. deep with sand, and washing out the miners from the heading. These potholes were, however, always exhausted after a short period of pumping.

In the soapstone formations which were usually fairly dry, if anything happened to cause a fall of the ground on account of bad timbering, it was immediately followed by water which made the ground excessively heavy. The water in the hard tepetate formation has at times been so strong that in some lengths it has been almost impossible to get the workmen to work, owing to their inability to see or use their tools on account of the steady downpour of water, which came through the tepetate as if from a shower bath under very heavy pressure. In these cases shifts had to be cut down sometimes to four hours.



Cross-Section in Heavy Ground Requiring Full Set of Timber.

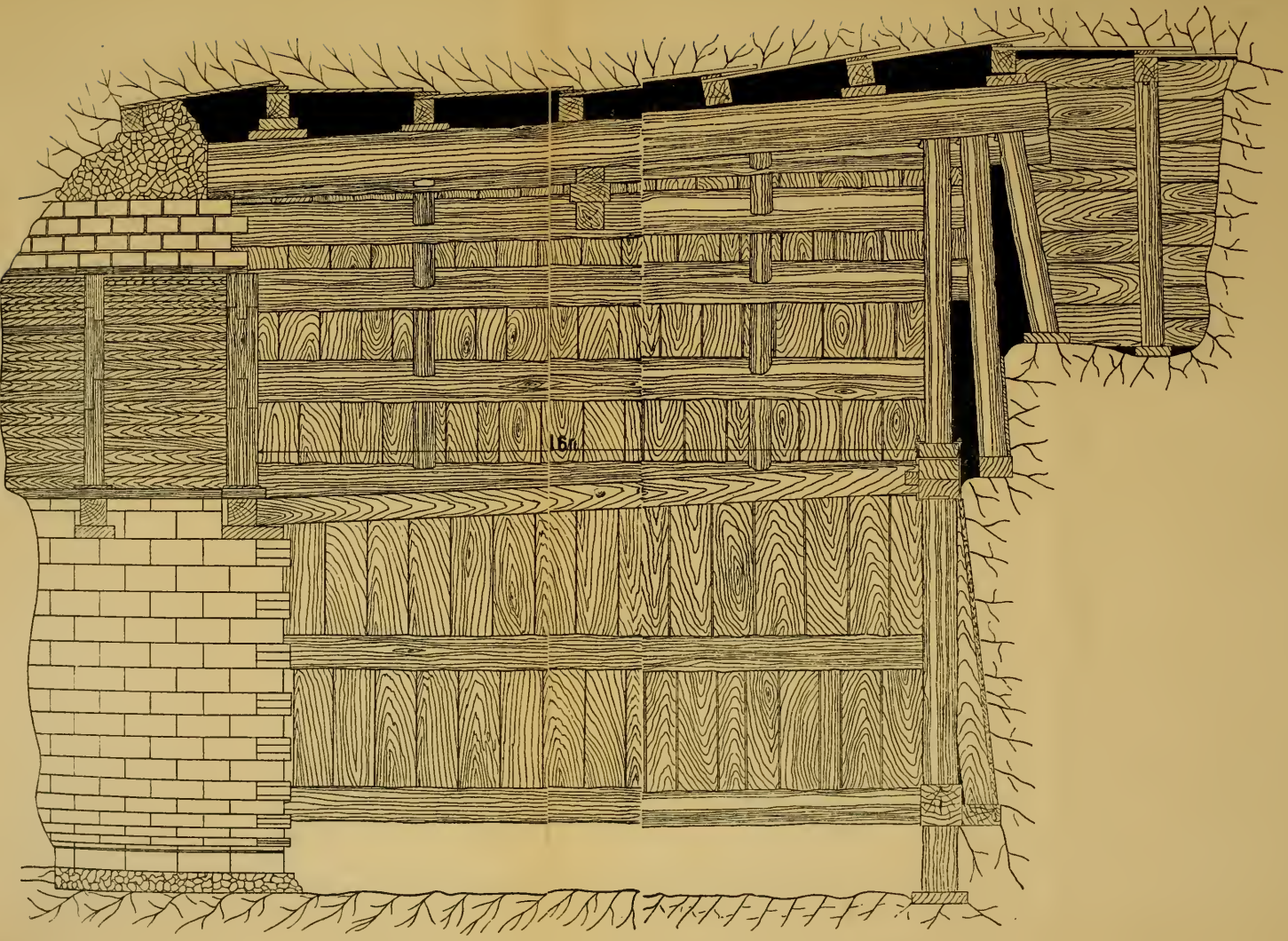
Timbering in Tunnel.—As will be gathered from the description of ground encountered, it is necessary as a rule to take out the ground with what is known in tunnel parlance as a full set of timber (of course this is a very elastic term in one way, as it can be extended to embrace any amount of timber), but as a rule it does not mean less than two sills and generally means that all ground is held up and sustained by timber and none of it left to stand alone. The amount of timber usually employed has been as follows: nine bars, three of them drawing bars, stump props and nipper sill with props, large scarfed sill with props and bottom sill, judkins, stretchers, liners, cockroost and in a few instances rakers. The lengths taken out usually average 14 ft. of finished work, the sill being squared all the way from 15 ft. 6 ins. to 17 ft. The best progress up to quite recently, made in full timbered lengths was five lengths of completed tunnel per month or about 70 ft., and the best average in soft ground per month, four lengths or 56 ft. The local workmen were at first unable to attend to the timbering without being closely watched by English soft-ground miners night and day, and although they after a time picked up the general method they were for a long time so careless that it was unsafe to leave them alone without constant and careful supervision in the heavy lengths, as they could not at first be brought to see the importance of such minor points as packing, feathering, catching head trees on crown bar, stretching side trees, etc., all of which little omissions increase the weight of ground. With time, however, they have improved wonderfully and are now remarkably quick and handy. In the hard tepetate only five bars and a sill are used as a rule, the bars being taking out bars, but the tepetate in these cases was often so hard in the invert that as good progress could not be made as in the softer ground, requiring more timber. Dynamite could only be used sparingly in the hard ground on account of the timber overhead, and consequently the ground came out very slowly, as at first the local workmen did not show great aptitude in using the pick. Work was carried out to the best advantage in regular lengths in the soft soapstone ground and in the soft compact ground already mentioned, as this as a rule could be taken out with one sill and nine bars, the crown and thirds being as a rule drawing bars. Crown and third bars were usually given from 1 ft. to 18 ins. drop, so as to allow ample space for settlement if ground turned out very heavy. It may perhaps be well to mention that drawing bars

are used in heavy ground, and taking-out (or striking) bars in good ground. The names fairly express the difference between the two; the drawing bars are always placed so as to be entirely outside the work, the striking bars come on the second and third ring of brick work and are struck as the arch comes up to them.

The best progress of all until quite recently was made by means of working double lengths. This system of working double lengths was employed where the ground consisted of tepetate that required timbering merely to keep the ground in place, and where, if the ground was kept in place, it did not suffer any movement that would be likely to throw extraordinary weight on the bars. It was necessary for the use of this system that a bottom heading should have been previously driven, the necessity for which will appear later.

In ground of the character just described a length usually required nine bars and a top sill and sometimes liners, judkins and stretchers being also used, but no cockroosts, the bars being all taking-out bars, and one crown bar and two crown bars being used alternately. The top heading was always driven further ahead than customary, to admit of this system which really had for its only requirement the putting up of bars in two lengths at a time. When working a single length, after the length has been lined up, if the bars are drawing bars, they are pulled ahead, and if they are striking or taking-out bars, they are taken out as the arch is built up; but in either event no operations are commenced for putting up the bars in the following length until the completion of the single length under construction. With the double-length system, when one length is keyed up, the next length probably has seven bars and the sill in, and the top heading is being prepared for the crown bars in the next immediately ensuing length, the said bars coming from the length just keyed up.

When using the double-length system, by the time a length is excavated requiring, say, one crown bar, two thirds, two fifths, two sevenths, and is ready for the masons, there will be in position in the top heading for the new length on each side of the crown bar two other crown bars whose ends can be seen projecting in the diagram and the position of which explains the necessity for using one and two crown bars alternately, as the bars have to be sandwiched in between each other. The two crown bars in the top heading are propped on the sill of the length the masons are about to enter, and at their extreme end


15m.

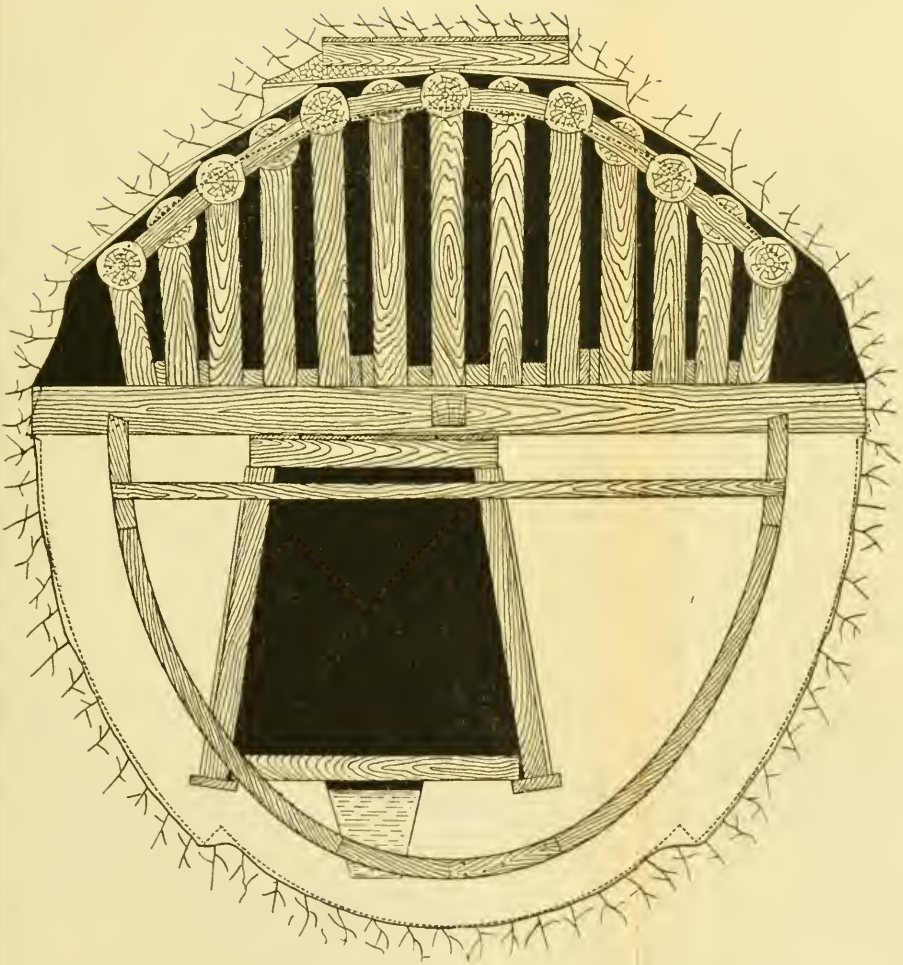
rest on short stump props. If they are not sandwiched in between the crown bars and the third bars of the length the masons are about to enter, they would not be able to be propped on the sill. These two crown bars come from the finished length immediately behind the length about to be lined, and are propped high enough to clear two rings of the arch about to be constructed in the excavated length. When the masons have started work in the excavated length, polling for the fourths is proceeded with in the top heading for the new length; and when the side walls are up in the excavated length, ready for the byats, the fourths are hauled ahead from behind and put in, while the ribs are being set for the arch in excavated length. Directly the arch is started, polling is proceeded with in the new length for the sixths and eighths, a nipper sill and props being at the same time placed in position to catch the bars, and a lining setting being placed in the bottom heading to sustain the nipper sill above. As the arch is finished and keyed, the sixths and eighths are probably in and the main sill also in and propped. The fourths and crowns in the new length are caught on the arch as it comes up, while bar holes are left for the sixths and eighths, so that by the time the length under construction is keyed up, the top heading has been converted into a new length with eight bars and sill in, and the hardest part of the work of excavation finished. The one crown bar from the keyed-up length is now moved ahead into the new top heading, to be sandwiched between the two crown bars, and the operation proceeded with as before, with the exception that in this length seven bars will be used instead of eight, for reasons already given. The drawings (Plates XXIII and XXIV) show very clearly the arrangement of timber in the double-length system.

The necessity for the bottom heading now becomes apparent. While the length with the sill in is being completed, it would be impossible to commence a length ahead of it if it was necessary to take the dirt from excavation in the length ahead through the back length, as it would too seriously interfere with the progress of the work; again, while the masons are on the arch of one length, it would be impossible to take dirt out from the length ahead through the length being lined without interfering with the masons. By the use of the bottom heading however, a separate communication can be made in either length by means of knocking a hole through from the top heading and loading

the coaches underneath. This system of double lengths has been very successful, as much as eight lengths in one face, or 120 ft. of complete tunnel, have been constructed per month. This system has latterly been still further extended with considerably better results as regards speed, as will be referred to later. In using this system, extra care has to be taken and the timbering watched carefully. The bottom heading must have lining settings placed under the nipper sills, and all the settings must be carefully stretched and watched, as there is always a chance of the stump props under the bars pushing through into the bottom heading. Of course this system cannot always be used, as it is not frequent that the ideal material, just soft enough not to require the use of explosives, and not hard enough to stand with a small amount of timber, is encountered.

Timbering in Top and Bottom Headings, and use of Headings.—The timbering for top and bottom headings is practically the same; the top heading is driven for the drawing of bars in the construction of ordinary lengths; the bottom heading, by far the more important of the two, is driven for three important reasons: First, the connection of shafts with the open end, as, immediately the said connection is made, the pumping in the shaft connected with can be discontinued, and also for the connection of shafts not in communication with the open end; second, to enable break-ups to be constructed, a point which will be touched on later; and third, to enable the double or treble-length system to be worked in the manner already explained.

The dimensions of the bottom heading are as follows: 6 ft. 6 ins. high; 5 ft. at top, or 4 ft. in the clear; 7 ft. wide at bottom, or 6 ft. in the clear. In good ground it was possible to excavate 6 or 8 ft. ahead, putting in settings as heading advanced. In bad ground it was necessary to use the ordinary methods of driving polling boards ahead, working temporary head trees, etc. The majority of the heading, however, was driven through fair ground, which allowed of excavating 6 or 8 ft. ahead, and putting in settings as heading advanced. The side trees, which were 6 ins. by 7 ins. by 6 ft. 6 ins., were cut to bevel at a saw mill, so that, when they were fitted snug to a head tree of 7 ins. by 7 ins. by 5 ft., they would then have the required batter. In good ground, polling boards of 1 in. by 12 ins. by 5 ft. were used; in bad ground, polling boards of 1 in. by 1 ft. by 3 ft. 6 in, or 1½ ins. by 1 ft. by 3 ft. 6 in.



Cross-Section in Light Ground, Showing System of Double Lenoths.

In good ground, settings were about 4 ft. apart, with sides and top lined with 5-ft. boards, lining settings being put in between each original setting as the heading progressed. In the bad ground, where the settings were only 3 ft. apart, lining settings were also used. As a rule, the bottom heading was driven 2 ft. above the invert of the tunnel so as to keep the road above the dead water of the tunnel. As already mentioned, this heading was required for purposes of drainage from one shaft to another; it was therefore necessary to cut a grip or drain in this heading 2 ft. deep, as otherwise, on account of the grade, the water in the shaft just communicated with would be some 2 ft. too deep, when the tunnel began to be constructed. The excavation of the grip necessitated the use of good sleepers under the road, to prevent it from falling into the grip, and these sleepers were made at the same time to serve the purpose of stretchers at the bottom of the side trees, between whose sides they were wedged.

Progress in Heading.—The average daily progress in bottom heading for the year ending the 1st of June, 1893, was about $5\frac{1}{2}$ m., the daily progress ranging from 4 to 6 m., and on a few occasions being as high as 7 m. Prior to June, 1892, the average daily progress in heading was only about $1\frac{1}{2}$ m.; and whereas, the former progress compares favorably with work done under similar conditions anywhere, the latter is far from doing so. The slow progress made at first with heading was due to a variety of causes, among others the following:

First.—To attention being mainly devoted to working from each shaft, using pumping machinery for dealing with the water, on account of the short time allowed for the execution of the work.

Second.—To the inexperience of all concerned in driving this class of heading; the ordinary soft-ground English miner proving useless directly he was put in a heading where the ground was fairly good and rapid progress—not timber—required, and the local labor proving very inefficient from want of previous training, when it came to hard pick work and constant application.

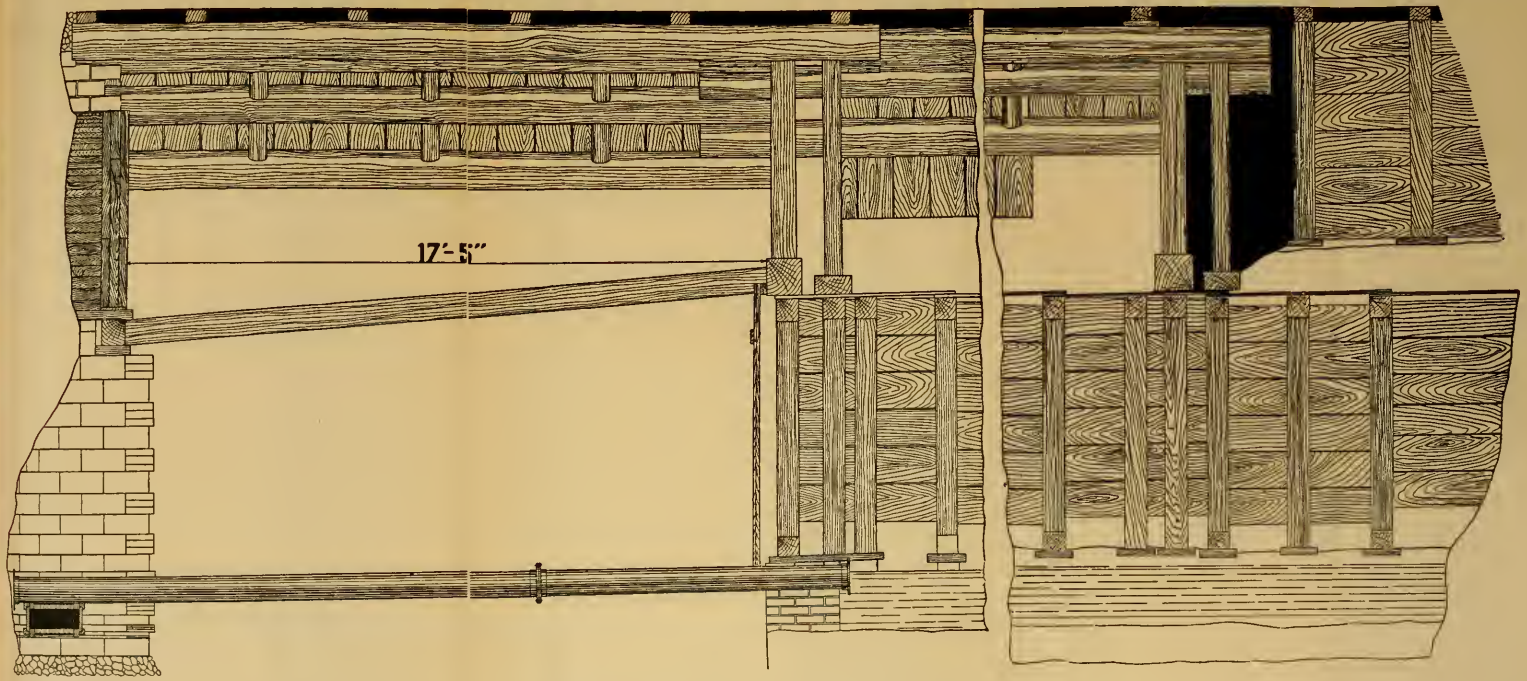
Third.—To the difficulty caused by the heading being originally driven in the center, rendering it possible to use only one road in the tunnel, so that, when the tunnel and heading were being constructed at the same point, preference had to be given to the tunnel traffic to the entire detriment of the heading traffic.

Fourth.—To a short-sighted unwillingness to pay high-enough prices for driving of heading.

Fifth.—To the want of sufficiently careful organization and of the minute attention to details necessary, no arrangement having been possible at first, or, at least, made, for the working of regular shifts with carefully picked men specially adapted to the work. Later on, when a special feature was made of driving bottom heading, very careful attention was given to the matter, and the difficulties and faults mentioned and others were gradually overcome and corrected.

The extraordinary speed obtained latterly, higher undoubtedly than in any similar work, would appear to call for some other explanation than that given, but can only be attributed to the following additional reasons: First and most important, constant attention and personal supervision night and day, not only by gangers, foreman, etc., but also by the agent and engineering staff, measurements being taken every morning, heavy fines imposed for delays, and every inducement given to push on the work. Attention was given to the smallest details in connection with the work, the track in the tunnel was most carefully laid, the provision of cars in proper number, and the winding arrangements and handling of material underground and at surface, studied to ensure no hitch or delay of any kind. Another reason was (as already mentioned) that, as more of a feature was made of the heading, it became possible to dispense, in a measure, with pumping expenses for the purpose of connection of shafts, and a higher price could be paid for the labor employed in the heading, which was far more than compensated for by the advance made. When, after considerable opposition, eight-hour shifts were introduced instead of ten-hour, the progress went up to $5\frac{1}{2}$ m. per day very quickly. It must be borne in mind that the local labor was at first comparatively ignorant, both as regards tunnel and heading work, and had to be taught and trained; it proved remarkably quick and imitative, and under good direction and with proper tact and patience is capable of almost anything.

In working eight-hour shifts the miners were kept constantly in the face and not allowed to leave until the expiration of their time. There were usually two or three miners in the face, with from 6 to 10 men, varying with the distance, at the cars removing dirt, with a native foreman to supervise generally. All these men were changed every



SECTION IN LIGHT GROUND SHOWING SYSTEM OF DOUBLE LENGTHS.

eight hours; in addition there was usually an English or American foreman to attend to putting in settings in line and level, and to the receiving and carrying out instructions, etc. This foreman was paid a shift and a half for each 24 hours, and was supposed to be there when needed. In addition to the men in the heading there was a gang of about six men behind cutting grip, laying road, putting in intermediate settings, etc., and also a man at pit bottom to attend to ringing up of cages, etc., above; there were from two to six men at coaches at pit mouth, and one man to attend to landing of coaches from the cages.

When later heading was going well and organization complete, the task every 24 hours was set at 6 m., and the subcontractor fined if the task was not completed; of course, where there were special reasons, such as exceptionally heavy ground, the task was not insisted upon. Dynamite was as a rule required in quantities of from 2 to 3 lbs. per lineal meter, or about 1 lb. per cubic meter.

The heading was all carried out by subcontract at so much per meter, the work being left to specially selected local subcontractors capable of pushing and controlling the men.

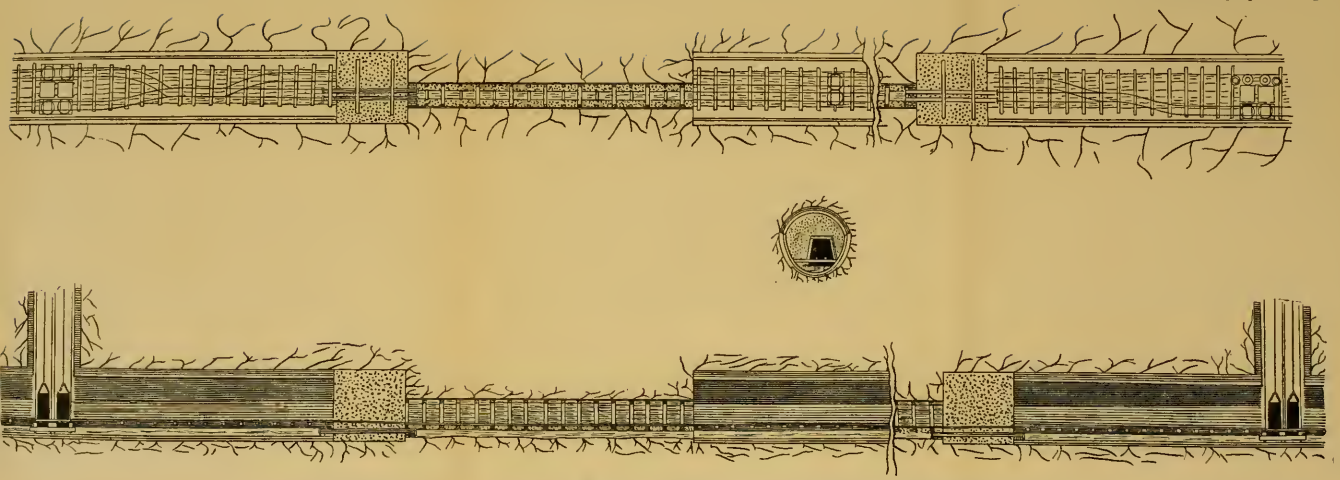
Lining of Lengths.—Immediately a length of ground was excavated for tunnel construction, a frame (shown on Plate XXIII), the exact shape of the invert, was set at the leading end of the excavation to the correct level and alignment of the tunnel, lines being stretched between this frame (which is notched at the level of each course of artificial blocks) and the blocks in the finished tunnel in the length behind. The masons then commenced to lay the backing, and on top of it the blocks, lining up with the lines until the invert and side walls were completed, the special blocks referred to as having their upper side parallel with the radius of the arch being laid last. Holes were left in the last course but one, at intervals of 3 ft. 6 ins., to receive the byats, the byats were footed on wooden foot blocks about 2 ins. thick laid over the cement blocks, the foot blocks forming a sort of pad in the cement blocks, as otherwise it was found that the weight of the arch would often crush the sharp edges of the byats into the blocks, causing them to crack and necessitating their renewal. On the byats being placed in position, 3-in. planks were laid along their ends parallel to the axis of the tunnel, and on these the ribs are set and wedged up to the required level. The ribs are made of two thicknesses of 2-in. plank bolted together and cut in sections, to form the required circle; the leading

rib is always made of three thicknesses, to sustain the extra pressure it frequently receives, owing to the crown bars resting on it. Laggings 2 ins. by 4 ins. by 16 ft., more or less, are then placed on the ribs, to receive the brick work and continued to be placed as the arch is carried up.

When the arch has been carried up on both sides till the two sections are only 1 ft. 6 ins. apart, it is necessary in ordinary practice for the force of masons to stop, as only one man can work conveniently and finish the arch, or the keying up. In ordinary practice it is usual to use pieces of lagging of short length that will reach from one rib to another instead of using laggings of the full length as before, thus enabling the mason to get in between the ribs and key from one to another. Here block laggings are used when the arch is stopped as mentioned above the key. These block laggings are 18 ins. long and about 1 ft. wide, with grooves cut in the upper sides, and, instead of being placed like the others parallel with the axis of the tunnel, they are placed at right angles to it. By using these laggings the mason can key and pack much more satisfactorily, as when one block lagging is placed in position, it being only 1 ft. wide, he is able to work in and over to much better advantage than if he was working on the older system and was obliged to stretch from one rib to another, a distance of 3 ft. 6 ins.

The question of packing above the arch—a most important one—was one of great difficulty at first, owing to the difficulty of persuading the local workmen to execute it properly. Where striking or taking-out bars were used it was easier, as it could be done simultaneously with the construction of the arch; but where drawing bars were used, and a feather or pillow of brick had to be constructed on each side of the crown bar all along the arch, to sustain the polling boards when the crown and third bars were struck, it was a matter of greater difficulty.

The average number of men employed at one time in a length is about eight, including the operations of excavating, lining, etc., the least number at the commencement of opening out top heading being four, and the greatest number, while lining arch, about fourteen. At the commencement, as already mentioned, while opening out the top heading, some four men are employed, and as the ground opens out, the number goes up to six and finally to eight men, while excava-



Shaft-to-Shaft Ground Plan, Showing Method of Alignment of Road, Arrangement of Headings, etc.

ting the invert. When the masons go in, about six start at first, with a helper to each, the number of masons on side walls and arch increasing finally to eight, with six helpers, which number drops down to two on the keying of the arch; this, of course, does not include foremen, inspectors, and men at the coaches, the latter varying from three to six pairs according to the rapidity with which the dirt is excavated and the material used.

The excavation and lining of lengths is all done by subcontract at so much per meter, prices varying according to nature of ground, quantity of water, distance from shaft, etc. In fact, all work, both at the surface and underground, is done by subcontract as far as possible, the results obtained being far more satisfactory than when paying day wages.

Roads in Tunnel.—In arranging the road two requirements had to be considered: First, the necessity of having under the road in the invert sufficient space for an ample channel, to carry away all water that might be encountered without danger of flooding the road; second, the necessity of having the road sufficiently low, to allow of tunnel coaches passing under byats set in the side walls, to support the ribs for construction of the arch. The position of the roads is clearly shown on Plate XXV.

For the track through the completed tunnel a 9-ft. sleeper met all requirements and gave an available width of about 8 ft. for the road, and allowed good arrangement of tracks. Driving the bottom heading in the center of the tunnel, as was done at first, compelled the road to be laid in the center of the tunnel, and, as all the traffic of any break-ups that might be in course of construction ran over this road, it became necessary to put in sidings at all faces in construction, so that if building materials were being used at one face, they could be switched on to a siding, and so leave the main track free for the general movement of dirt, etc. Putting the road in the center with a gauge of 2 ft., and a car 3 ft. wide, only gave 2-ft. 6-ins. clearance on each side, which was not enough for another track, and it became therefore necessary when break-ups came to be generally worked to adopt some other plan, and the heading was then driven 18 ins. off the center, enabling a main line to be run through the heading from shaft to shaft, and devoted solely to the loading of dirt and preliminary movement of material, a siding being put in at each ordinary work-

ing point from a shaft where cars could be unloaded of material and loaded with dirt without interfering with general traffic. For the break-ups an auxiliary line was used, but instead of points and crossings a system of turn-tables was adopted. When a break-up is started and the preliminary length constructed, a double track is required at once; but as in a length of 15 ft. it was impossible or inconvenient to put in points and crossings available for either face of break-up, a straight parallel track was laid and two turn-tables put down, one on the main line and the other on the new track. By this means every facility for moving from one track to the other was given and as soon as bricks, etc., arrived for the break-up length they were immediately run on to the turn-table on the main line and turned on to the parallel line, leaving the main track free, a most important requirement, as when bricklayers were in the break-up, if a second track was not available, all cars moving on the main line would have to wait while the cars carrying material for masons were unloaded. If the lining of lengths in the various faces had proceeded in regular rotation, it might have been possible to arrange the traffic in another manner, and, by sending trains of cars loaded with material to a certain face, and then requiring them to pass on empty to another face, to return full of dirt, avoid some of the difficulties mentioned; but as the chances were that these trains would have to pass through two or three lengths in process of excavation before re-arriving at their destination, and then have to come back to be loaded, it was practically impossible to do so. Considerable attention was devoted to the question of track, as smart and proper handling of material and dirt was indispensable if rapid progress was to be made. The following example from practice will explain this necessity perhaps more forcibly:

Between Shafts Nos. 15 and 16 there were, at one time, three break-ups in construction, besides one face of tunnel in construction to the north of No. 16, one to the south of No. 16, one to the north of No. 15, and one to the south of No. 15; that is to say, 10 faces of tunnel in construction at the same time between two shafts. Ten faces implied, at a moderate estimate, the moving of some 7 000 cu. yds. of dirt, 400 000 bricks, 20 000 cement blocks, 5 000 cu. yds. of stone, and 700 cu. yds. of mortar, besides 50 000 ft., B. M., of lumber, together with rails, tools and other materials, in some 26 working days, and the delivery of much of the material to points distant from the shafts. It was

necessary to distribute the working equally between the two shafts; that is to say, Shaft No. 16 dealt with No. 16 north face, No. 16 south face, north and south faces in break-up No. 1, and north face in break-up No. 2, *i. e.*, five faces. Shaft No. 15 dealt with north and south faces of No. 15, south face in break-up No. 2, and north and south faces in break-up No. 3. The brick, etc., required for a length being lined in north face of break-up No. 2, had to come from Shaft No. 16, through south face of No. 16, north and south faces in break-up No. 1, to get to their destination, with perhaps all these lengths full of men. Five faces meant a monthly construction of, at the very least, 330 ft. of tunnel, or an extraction of about 3 300 cu. yds. of dirt per month, and the provision of 200 000 bricks, 10 000 blocks, 2 500 cu. yds. of stone for backing, and 350 cu. yds. of mortar, not taking into account the movement of timber, men, rails, etc., and as there were only some 26 working days and nights in the month, this implied the handling of one car every two or three minutes. The sleepers used in the track laid through the finished tunnel were about 4 ins. by 8 ins. by 9 ft., spaced some 3 ft. 6 ins. apart. Decauville track, with 12-lb. rails and steel sleepers, was employed, and the rails were also spiked to the wooden sleepers. The steel sleepers could have been dispensed with, but they more than paid for themselves by giving additional stiffness to the road and keeping the track to accurate gauge; the wooden sleepers got sodden, and the spikes would draw unless the track was helped and kept together by the steel sleepers. Most of the points and crossings used were ready riveted, and all that was necessary to move them forward was to take them up bodily, put them on a car and drop them down again where wanted, spiking them in places.

In the bottom heading the track was laid on wooden sleepers 3 ins. by 6 ins. by 6 ft., the sleepers also serving as stretchers, to keep the side trees apart, and, as bridges, to keep the track well above the drainage grip mentioned before. The steel ties were here again very serviceable in stiffening the track and keeping it in gauge.

Drainage in Heading.—The drainage of the tunnel, and more especially of the bottom heading, was a very important point in connection with the successful prosecution of the work, especially at the open end of the tunnel, where work was being done frequently from various shafts at the same time. It will be remembered that regular tunnel faces, break-ups and bottom heading are all being carried on

at the same time, and, where the water had to be drained away through the open end of the tunnel, arrangements had to be made to keep the water-way clear through the work in all its various stages of progress, the principal difficulty being carrying the water through the lengths in which invert was in course of construction. Theoretically, the water ran at the level of the finished tunnel invert, but it was necessary to excavate below this level, to get in the masonry necessary for the construction of the invert, and whatever stream of running water there might be flowing in the tunnel at this particular point had necessarily to be carried across the length of the invert while in construction. At times, when there were as many as three break-ups in addition to two regular faces in work between each pair of shafts, and when two or three shafts were in operation at the same time at the open end of the tunnel, frequently with half the total number of lengths being lined at the same time, the greatest care was necessary in carrying the water over the various lengths of invert in construction, so as to avoid damming back the water more than was absolutely necessary. The water discharged through the open end ran on the finished invert naturally at a depth never less than 12 ins. There was, therefore, this initial amount of dead water to contend with from the beginning; higher up, above one set of break-ups, the water would probably be dammed up a further 6 ins., giving a total depth of dead water of 18 ins, and so on, with the result that, in the face where bottom heading was being pushed forward, the water frequently reached a depth of 2 ft. It was found necessary to drive the bottom heading at a level some 2 ft. above the level of the tunnel invert so as to keep the floor of the heading dry as far as possible. In one case, on approaching Shaft No. 12, the level of the heading had to be raised still higher, on account of the large increase in the amount of water discharged, due to filtration, etc. On heading being communicated between any two shafts, the level of the same, being 2 ft. above the tunnel invert, prevented the water from the shaft just communicated with from flowing away below that level; but seeing that it was indispensable that the water should be allowed to flow away at the level of finished invert in order to render the construction of same possible, a grip was cut in the bottom of the heading 2 ft., either after completion of the heading or carried along simultaneously with it. This grip (as previously explained) required extra timbering as, more

especially where the ground was soft, the sides of the grip were liable to cave in and let the side trees down. A special gang was always employed solely for the purpose of keeping this grip free from mud, dirt, etc., due to material falling from the cars and other reasons, as, should any obstruction occur in the grip, all work above the point choked became seriously inconvenienced, and in some cases might be stopped.

The total discharge of water at the tunnel mouth varied from 1 500 to 3 000 galls. per minute. In excavating an ordinary length and putting in the invert between pumping shafts, water was, as in the case of the open end, always found in the excavation, which was carried as a rule from 15 ins. below the level of the finished invert. On completion of the excavation necessary for the invert masonry, the dead water from the finished tunnel would also immediately run into the excavated length, if means were not taken to keep it out. The entrance of this water was avoided by the use of a dam placed at the end of the last length of constructed tunnel, which backed up the water and prevented it from running into the excavated length. Any water, however, that might be encountered in the actual ground excavated below the invert level or that seeped through had to be pumped over the dam with small hand pumps into the finished tunnel. Working in ground where only shaft faces were in construction, with no break-ups, there was no necessity for carrying the water over the work in construction, but at the open end, as already indicated, it was necessary, also, to deal with the water coming down from above, from all break-ups, faces, etc., and in these cases a dam had to be constructed, not only in the end of the finished tunnel, but in the heading itself, and pipes laid from the dam in the heading to the dam in the tunnel, or *vice versa*, so as to carry the water over the length. At first this did not present any great difficulty, as two 12-in. pipes proved sufficient to carry the water; but later on, when the water largely increased in quantity, the pipes employed had to be largely supplemented, and, latterly, a large launder used, which seriously interfered with the small space available for the masons. When the ground in the heading was soft or of a sandy character, it was found extremely difficult to construct a satisfactory dam. The earth round and under the same would wash away and the water from the heading find its way into the excavated length, filling same and necessitating the reconstruction of the dam, relaying of pipes, etc. This working in of the water, in spite

of all provision, occurred sometimes as often as two or three times in bad ground during the construction of a length, and the difficulties were often further increased by the action of the water washing round the bottom sill props and undermining them. The dam placed in the invert of the finished tunnel was a comparatively simple matter. At first it was constructed of bricks and clay, which were removed on the completion of each length; subsequently, however, a hollow dam was constructed of boards made to fit exactly the shape of the invert. This could be placed in position very speedily and weighted down with clay placed inside; and directly the invert of the next length was finished, it was moved forward before the sleepers were placed in position. This effected a great saving in time and labor. The size of this dam was about 2 ft. 6 ins. high and 8 ft. long, constructed of 1½-in. planks.

The quantity of water encountered in excavating the ground for the laying of the invert varied very much, it sometimes taking as much as 6 shifts and from 8 to 10 hand pumps to pump out a length before the masonry could be laid, while on several occasions the masonry of the invert had to be laid in some 12 ins. of water.

The plates which accompany the paper show fully the arrangements in connection with the dams, levels at which heading was driven, etc.

Quick Handling of Material Above and Below Ground.—This was a point to which very considerable attention was given, although nothing specially new was used in the way of winding engines, cages, etc. The chief difficulty consisted in proper organization and discipline of local labor, in securing capable drivers for the winding and other engines. The head-gears for the shafts were of the usual type, some 50 ft. high, with two floors, one at the ground-level and the other at about 15 ft. above. The lower floor was used entirely for the cages carrying materials necessary for construction, while the upper was used only for the coaches carrying dirt, etc., extracted. A turn-table was provided for each cage, with a switch and double track to both sides of the shaft, double cages being used in each shaft. At the pit bottom four turn-tables were employed, two to each cage, one on each side, thus affording double means of exit and entrance and communication with the double track in the tunnel. The turn-tables in all cases proved more convenient than switches, where it was possible to employ them.

The arrangement of the turn-tables and of the tracks is also shown in the plates accompanying this paper.

Ventilation.—Ventilation was a point of very considerable importance, especially in pressing on with the heading with all possible speed. Root's blowers, No. 1, 14 ins. by 22 ins., and 30 ins. long, with 8-in. inlet, were used, being worked either by a small separate engine or from the pumping engine. Spiral rolled iron tube, 5 ins. in bore, was used for carrying air into the workings. On any two shafts being communicated, the natural ventilation, if properly looked after, proved to be sufficient. Previous to communication, in some of the headings where a considerable quantity of dynamite had to be employed, and when the distance from the shaft was 800 to 900 ft., the air became so bad as to necessitate the use of two blowers, one being placed at half the distance, exhausting the air, and the other at the face, blowing in air. Considerable difficulty was found in keeping the pipes, joints, etc., in order, as the workmen, if the air was too cold, would frequently plug the pipe; or if at another point the air appeared deficient, would knock a hole in the pipe with a pick and thus satisfy their wants.

Cost of Tunnel.—The cost of the finished tunnel by the present system of working during the last year has averaged from $650 to $700 per meter. It is impossible here to enter into details of the cost, as this subject would fairly merit another paper. The cost of the tunnel has been exceedingly carefully studied and analyzed, and the percentage of the cost divided under a very large number of heads; but it is impossible to touch upon this matter satisfactorily without going into very detailed explanations, as the cost of the tunnel varied, and must necessarily vary, according to the circumstances under which it is carried out. If a tunnel has to be constructed within a specified time at the highest possible speed, necessitating the working from every possible point and the employment of pumping machinery, the cost must obviously differ immensely from that obtained where working is only carried on from the open end or at such points where pumping presents no great difficulties; while again, the latter cost will vary if the expenditure is limited to a fixed sum per month.

Labor.—Foreign labor was very extensively employed at first, it being utilized, not only in the tunnel in connection with the excavating and timbering of lengths, but also at the winding, pumping and other

engines, and largely also in the fitting shops, brickyard and at other points. Recently it was found possible to dispense with foreign labor almost entirely, with the exception of the English or American tunnel miners necessary for looking after the timbering, and even those were reduced in number, the only other foreign labor employed being the foreman in charge of tunnel masonry, the chief mechanic and two or three assistants, foreman of shops, with two or more good tool hands, foreman of the brickyard and one or two others. The agent, engineers, chief accountant, chief of traffic and some other members of the office staff, are English or American. Local labor, where it could be utilized in place of foreign, was found far more satisfactory, the men being more sober and attentive to their duties, and only requiring constant and careful supervision on the part of the agent and the engineering staff, as already mentioned.

General.—The progress made during the year ending the 15th of September, 1893, is as follows :

Meters of tunnel built	2 036.77
Meters of heading driven	4 420.74

There remained at that date only some 2 667 m. of tunnel to build, and 900 m. of heading to drive.

The greatest amount of tunnel built in any one month during that year was 242 m., and of heading driven, 450 m.; while the greatest advance in tunnel in any one face in a month was 55.50 m. with the treble length system, and in heading, 260 m. The unwatering of the tunnel is now effected entirely by the heading as regards the points in work, and the total discharge per minute is about 3 500 galls.

During the month of July last, heading was being driven in Shafts Nos. 7, 8, 10 and 11, and tunnel built in Shafts Nos. 11 and 12 ; in August, heading in Shafts Nos. 7 and 8, and tunnel in Shafts Nos. 10, 11, 12 and 13.

Latterly it has been necessary to drive the bottom heading again in the center of the tunnel, as the large wooden launder required to carry water through the lengths came into collision with the bricklayers' frame when set for building the invert, the size of the launder or trough being 21 ft. by 4 ft. by 1 ft. 6 ins., and constructed of 2-in. boards. In conclusion the authors of the paper wish to thank the contractor's agent, Mr. J. F. Toomer, for most valuable assistance afforded them.

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THE SANDROCK SEWERS OF ST. PAUL, MINN.

By GEORGE L. WILSON, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

Situated on both sides of the Mississippi River, the city of St. Paul includes every variety of surface, from nearly vertical palisades extending along the river for miles, to prairies, and from ground below high water in the river (which has a maximum flood stage of 19 ft. above low water) to the higher portions occupied as residence districts, which are from 200 to 300 ft. above the river. The situation of the residence portions on the high ground, on both sides of the river valley, overlooking the business district and the river for miles, is very beautiful; few cities equal, and none surpass, it in natural scenic beauty, as the panoramic views from its bluffs demonstrate.

A portion of the city area 90 to 100 ft. above the river forms a nearly level bench, comprising a district of some 1 100 acres and extending 4½ miles in length, with a width varying from $\frac{1}{5}$ to $\frac{3}{4}$ of a mile. It is of peculiar geological formation and contains a unique system of tunnels for sewers, water works and telephone cables, being, so far as known, the only extensive construction of the kind in America.

This plateau forms a shelf, so to speak, in the gorge of the Mississippi, and is a bench left when the river carved out its deeper and present channel. It is formed by the bottom and hardest portions of the Trenton limestone, of which ledges from 20 to 30 ft. thick remain under this area. This limestone is quarried and extensively used for inside or covered foundation work. Like most limestone, it splits easily, and in a few years disintegrates when exposed to the weather, so that it has been generally abandoned for use in situations exposed to the action of rain and frost. This Trenton formation was originally about 150 ft. in thickness in St. Paul; the portion eroded was of a soft shaly nature with some seams of hard stone, as shown wherever cuttings along the bluffs have exposed the upper strata, which, it may be remarked, abound in fossils.

Over the limestone in the higher parts of the city lie clays and alluvial soils of varying thickness, but in that portion which we consider there are only a few inches or feet above the rock.

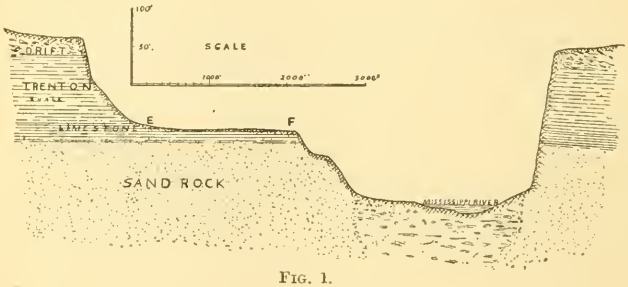


Fig. 1.

Under the Trenton lies the St. Peter sandstone; hardly a stone except in name, as it may be picked and shoveled without blasting. It is nearly a pure quartz sand, the lower strata almost white and the upper of varying shades of yellow. This formation, geologically known as St. Peter sandstone and locally as sandrock, is exposed along the river from 10 miles above to 20 miles below the city. It is about 130 ft. in thickness and lies approximately level from north to south and with a slight pitch to the west of 14 ft. per mile. The elevation of the top of this sandrock is 767 ft. above sea level and 84 ft. above the river, which has an elevation of 683 ft. above sea level.

In this sandstone, easily tunneled, there are many excavations for various purposes. Those of interest to engineers are the subways for

sewers, water mains and telephone conduits. In the first building up of the city the facility for draining the bench land by tunnels in the sandrock led to the construction of many drifts by private individuals, each running from some point at the bluff directly to the land to be drained, without much attention being paid to uniform grade or alignment and without any bottom lining. These have been abandoned as public sewers were constructed. The section of the river valley (Fig. 1) shows at $E\,F$ the portion of the city adapted for this tunnel construction and the geological formation before described.

In 1873 the city (then having a population of 25 000) began to build sewers in this sandrock. In those first built, the laterals were lined with V-shaped inverts. This proved unsatisfactory, and all now have a

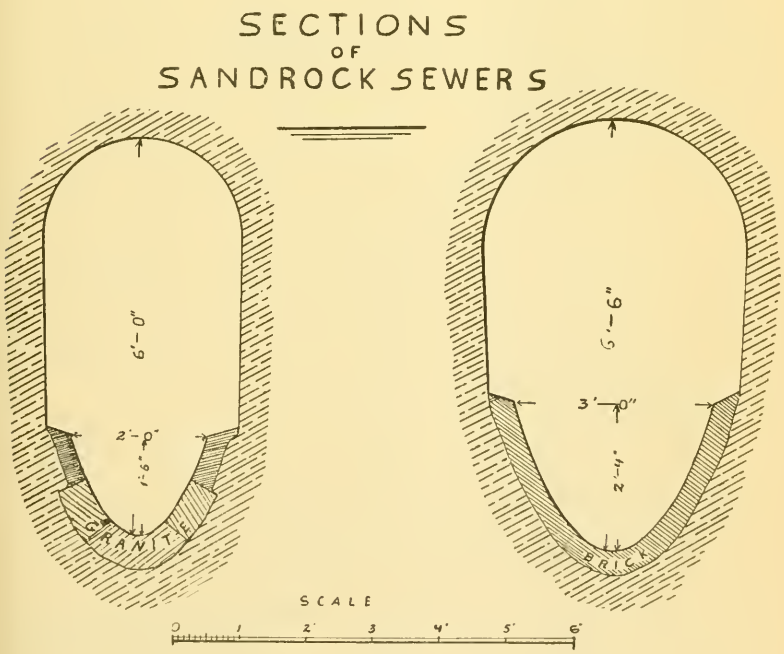


Fig. 2.

channel at the bottom lined with brickwork, usually of a parabolic section. The different sections used vary from 9 x 14 ins. to 4 x 4 ft., while the tunnels range from 2 ft. 6 ins. x 6 ft. to 7 ft. x 7 ft., all having a clear height of at least 6 ft. (Fig. 2). A main sewer running the entire length of the sandrock district acts as intercepter for the dry

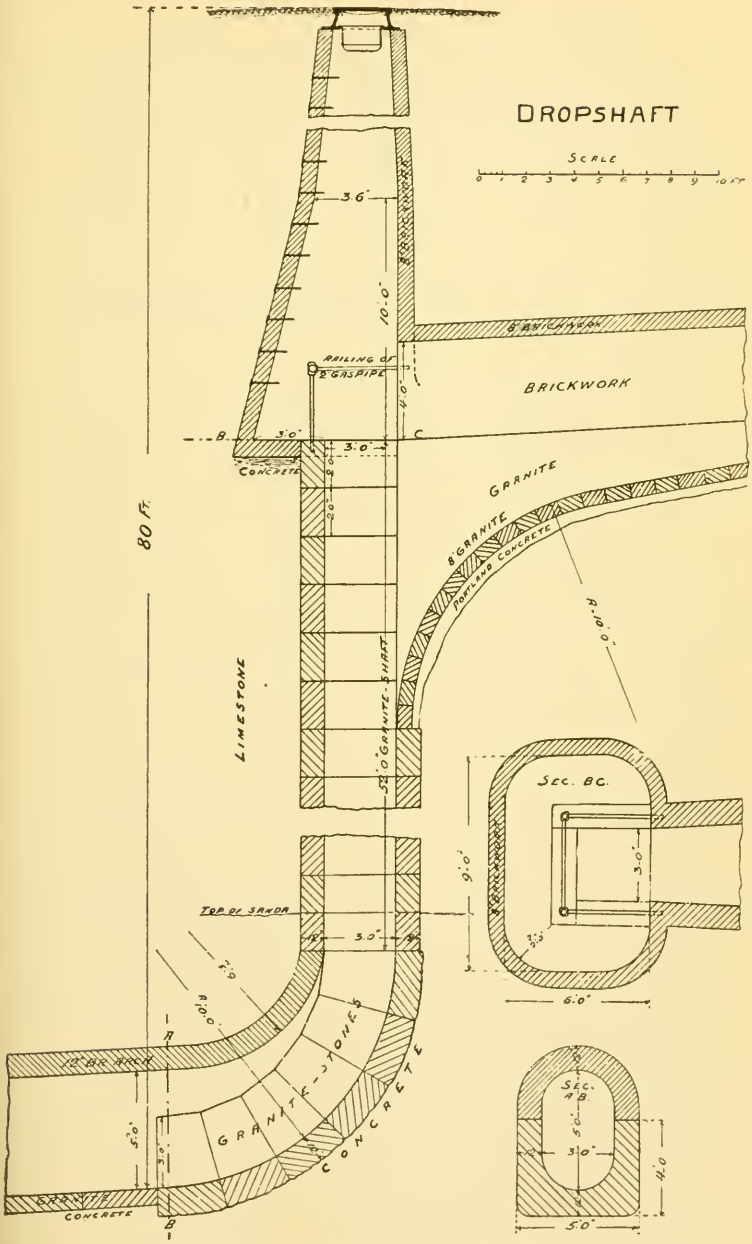
weather flow, while the storm water passes off through proper overflows. The invert, or channel of brickwork in the bottom, is of capacity to carry the ordinary flow and light showers. Storm water from heavy showers rises above the brickwork, but the rock is just hard enough, so that usually there is no appreciable scour. In many of the sewers the pick-marks of original construction are still plainly seen along the sides after 10 and 15 years of use. In places, however, the sandrock is soft enough to require a complete lining; in fact, it is probable that some time in the future these tunnels will be completely lined with brickwork and enlarged to serve as subways for other purposes in addition to their use for sewers, as has been done in Paris.

The grades used range from 0.1 ft. to 10 ft. per 100 ft., the rate of 1 ft. being preferred for the laterals. The rate of 10 ft. per 100 ft. is a necessity for getting down to the river in some of the overflows. On the steepest grades granite lining is used. In passing from open-cut surface sewers on the high ground to the sandrock sewers, difficulty is found in making satisfactory connections; generally a vertical drop in a granite-lined shaft is used (see page 199), or by a "slope" from the upper to the lower sewer if the depth is not too great. The bottom of the shaft is preferably a well at bottom instead of the section shown. The limit of economical construction is where the grade brings the roof of the sewer against the overlying rock, or the depth of limestone and earth above is such that it is too expensive to reach the tunnels from the surface. The views on Plate XXVI show actual construction in two of the sewers.

The depth from open-cut sewers to the tunnels, which usually end at the foot of the bluffs, is from 20 to 75 ft. Through the sandrock district the depth to sewer from the surface is between 25 and 60 ft.

In the construction of the tunnels, shafts are sunk at street intersections, from 300 to 600 ft. apart. These are built up with brickwork from the solid rock to the street surface and provided with manhole covers, and at convenient points with iron ladders for access to the sewers.

The lines are transferred from the surface by plumb-bobs in the shafts and fixed below by wooden plugs placed in the roof of the tunnel. Grades are given on similar plugs placed on the sides. The drifts are opened through between shafts, then trimmed to form, and the bottom carefully shaped to fit the brickwork, which is then laid accu-


DROPSHAFT
SCALE
0 1 2 3 4 5 6 7 8 9 10 FT
3.6'
10.0'
8" ANCHOR
RAILING OF 8" GAS PIPE
4.0'
BRICKWORK
B
C
3.0'
3.0'
CONCRETE
GRANITE
8" GRANITE
PORTLAND CONCRETE
10.0' R.
80 FT.
LIMESTONE
52.0' GRANITE SHAFT
SEC. BC.
9.0'
3.0'
6.0'
TOP OF SAND
3.0'
7.0'
10.0' R.
GRANITE-STONES
CONCRETE
5.0'
3.0'
CONCRETE
A
B
SEC. AB.
5.0'
3.0'
4.0'
5.0'

rately to grade and line. Owing to the short length of headings, usually no artificial ventilation is required, more particularly as most of this work is done in the winter, as labor is cheaper at that time and this is work that can be done then better than at other seasons. When ventilation is required, a small rotary fan is placed at the surface with 3-in. air pipe leading down to the heading.

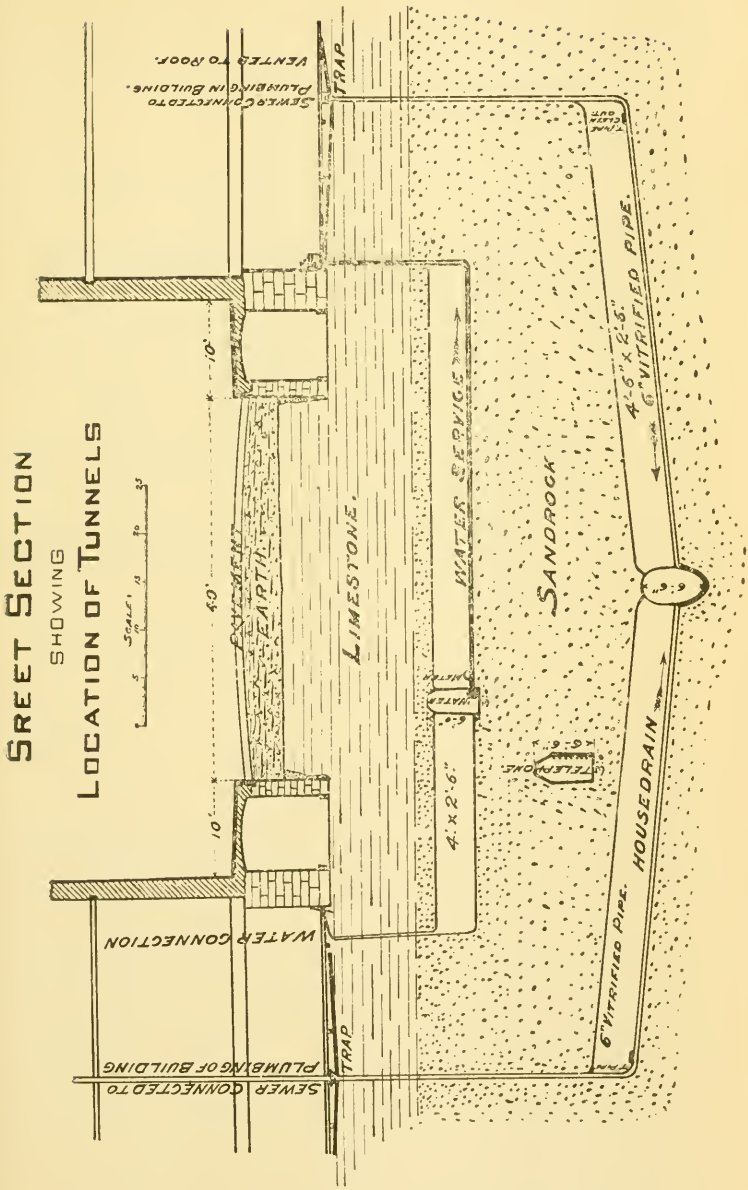
The tools used on this work are simple, the picks only are of special construction. The waste (muck) is loaded into buckets, wheeled to shafts, and hoisted by windlass operated by hand-power. The amount to be removed at one time being small, this is found to be the most economical method.

As to cost, the price of excavating and removing waste, use of tools and lights, averages $1 10 per lineal foot for smaller sizes; sinking shafts, $3 per foot in depth; brick lining laid in American hydraulic cement, $20 per M. The average cost per foot of all sizes may be put at $3, which will include shafts and catch basins; the cost of these with connection to the sewer is $150 each.

There are 20 miles of these subways in the city at present, and a considerable part of the area mentioned is not yet built up. About $300 000 has been expended in this work to date. House connections are made for a price of 85 cents per lineal foot of horizontal and vertical distance. This includes the 6-in. pipe which is laid to the main sewer.

The house-drains are connected with the main sewer through a small tunnel at right angles to the street, running back to the property to be drained. A 4-in. or 6-in. drill hole is made through the rock, the plumbing connected at the upper end, and a 6-in. or 9-in. vitrified pipe run from the lower end out to the main sewer. At the bottom of the vertical pipe a T connection with clean-out is placed, and the pipe in the side tunnel is covered with concrete. Connections with catch basins are made in a similar manner, except in the drift where a brick invert is laid instead of a vitrified pipe (see page 201).

Besides the sewer tunnels, there are some four miles of water pipes, in separate tunnels, located on the side of the streets and above the former. In size these are 3 x 6 ft. Pipes in these tunnels are of 4-in., 6-in. and 12-in. sizes. These pipes are in no possible danger from frost or surface disturbances, and the whole system is open to inspection or repairs at any time without opening the street. The method of


STREET SECTION
SHOWING
LOCATION OF TUNNELS
SCALE
5 10 15 20 25
10'
40'
10'
EXCAVATION
EARTH
LIMESTONE
WATER SERVICE
SANDROCK
4'6" x 2'6"
6" VITRIFIED PIPE
TIME CLEAN OUT
TRAP
SEWER CONNECTED TO PLUMBING IN BUILDING.
VENTED TO ROOF.
WATER CONNECTION
PLUMBING OF BUILDING
SEWER CONNECTED TO
TRAP
4'6" x 2'6"
TELEPHONE
WATER
6" VITRIFIED PIPE
HOUSE DRAIN
TIME CLEAN OUT

putting in service pipes from the buildings is very simple. A drift is run out at right angles to the street under the building to be connected, and a drill hole made from the cellar to the drift, and the service pipe run from the cellar to the main, where a meter is placed secure from meddling and easy of access.

The construction of telephone subways has been commenced. These are of the same general form and size as the water-pipe tunnels, and have space at the sides for eight or ten cables. For distribution to subscribers, one connection to the surface is made in each block and surface wires run in the block.

The city of Minneapolis has used a similar construction for its sewer outlet tunnels below St. Anthony Falls to a limited extent. Here it has been found necessary to completely line all the tunnels as the sandrock is more friable and holds more water in seams.

This is an account of how one city has been able to solve a portion of the subway question for a limited part of its area. There are, perhaps, no other cities having geological features that would make this plan feasible, for, like other engineering expedients, it has been worked out to suit the environment.

DISCUSSION.

A. F. Noyes, M. Am. Soc. C. E.—I would like to ask Mr. Wilson what method he used for ventilating the sewers?

J. T. Fanning, M. Am. Soc. C. E.—Mr. Wilson has mentioned that Minneapolis uses a similar system of sandrock sewers. The discharge of the main outfall sewers at Minneapolis is into the river below the Falls of St. Anthony. These outfalls are at a level about 100 ft. below the street surfaces drained by them, and the surface system of sewers discharges into the low level outfall in a vertical shaft. There is a strong upward draught through this vertical shaft which thoroughly ventilates the tunnel sewer below. The tail-races of the mills at Minneapolis are tunneled in the sandrock in a similar manner, and in this respect are similar to the Niagara power tunnel. Mr. Wilson said the surface rock in St. Paul is the Trenton limestone. The similar limestone in Minneapolis is about 12 ft. thick in the river-bed at the crest of the falls and rests upon the sandrock. The tail-races of the mills are tunneled immediately beneath the firm lime rock, and this rock forms the roof of each tunnel. The dam and forebay leading water

to the turbines rest upon the lime rock, and beneath the forebay a vertical shaft is cut to the tunnel below and the turbines are placed in these vertical shafts so as to discharge their water into the tunnel tail-races below. This system of tunneled tail-races is still followed at the mills in Minneapolis.

Desmond FitzGerald, M. Am. Soc. C. E.—Are the tail-races lined?

Mr. Fanning.—The original tail-races were lined with wood. The flow of water from the turbines does not usually fill the tunnel to the roof and the lining was not usually carried up so high as the limestone roof, but only a little above the ordinary level of water in the tail-races. Some of the older tail-races and the more recent tunneled tail-races are lined with masonry. The sandrock, usually called St. Peter sandstone, resists the effects of the atmosphere very well except near the mouths of the tunnels where frost action disintegrates it; but it is necessary to line these tunnels, to protect the rock from erosion by a current of water.

K. E. Hilgard, M. Am. Soc. C. E.—I do not know that I can add anything pertaining to the sewers, but I wish to state that I have always been impressed by the geological conditions existing at St. Paul, Minn. Over a great part of the city, they are very favorable to certain building operations. Removing a little top soil, the limestone is found in almost level ledges, easily removed and easily worked, furnishing sufficient and well-adapted material for cellar and basement walls to stand on the best of firm foundations.

Besides, everyone in St. Paul is proud of the beautiful white sandrock bluffs. Nature itself teaches us instructive methods. I have often admired the work of hundreds, nay, thousands, of birds in the soft sandrock, into which these winged creatures dig their little caves. Men, likewise, have taken advantage of this condition, and have at times dug out of this rock places to live in, and even in early times Indians have used caves as dwelling places that exist to this day.

D. J. Whittemore, Past President Am. Soc. C. E.—It would be very gratifying to the citizens of St. Paul could they feel sure that the sewers they have constructed in sandrock would not in time require lining.

In 1856–57 the Chicago, Milwaukee and St. Paul Railway Company constructed a tunnel through similar rock, at the dividing ridge between the Wisconsin and Mississippi rivers. Immediately after its construction it required timber support, and when this timber became decayed, it was found cheaper, and certainly safer, to build a new tunnel and line it with brick than to attempt to utilize the old one. The rock at St. Paul is so soft that one can bore into it with an auger, and birds excavate holes in it for their nests. Jonathan Carver over 100 years ago describes the rock as being the home of the birds. Perhaps some of the members will call to mind a very inter-

esting paper read at the Minneapolis convention by the late Colonel Farquhar upon the preservation of the Falls of St. Anthony, which falls, through erosion of this soft rock, was being disastrously affected.

Nearly 40 years ago I was camped with a party near an Indian cave in this rock mentioned by Carver, and there was then evidence inside it of continuous erosion..

I desire further to add that the line of the Chicago, Milwaukee and St. Paul Railway passes for a long distance along this sandrock bluff in St. Paul, and also at Fort Snelling, and that within the last three or four years great expense has been had in building retaining walls to protect against erosion of this rock, as each successive season through climatic effects would cause 1 ft. or more to shell off the steep bluffs and undermine the overlying limestone ledge, thereby endangering traffic. I state this as only tending to indicate that in time it may be found necessary to give the sewers in this rock at St. Paul an adequate lining.

George L. Wilson, M. Am. Soc. C. E.—In reply to Mr. Noyes' question, I would say that the sandrock sewers are ventilated by the shafts at street intersections. These serve as manholes and are all provided with ventilated covers.

In the drop-shafts the current of air whenever the water is falling is always down, thus drawing the air from the sewers above and forcing it in a stream into the sewers below.

The trouble spoken of by Mr. Whittemore is along the exposed bluffs, and is due to the action of sun, wind, and especially frost, neither of which affect the sewers. It is probable that at some time in the future the sewers may be lined, and the sections used are of such form that the upper part can be lined without changing the invert first put in. The rock at Minneapolis spoken of by Mr. Fanning is softer and charged with water, which makes the lining of the tunnels there a necessity.

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A FEW REMARKS ABOUT THE NIAGARA GORGE.

By L. L. BUCK, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

Various scientific societies have discussed this gorge and in some cases attempts have been made to estimate the length of time required by the river to excavate the chasm as it now exists. But there are some of its features which appear to have been overlooked in such papers as have come under the writer's observation, and which he has thought might be of interest to our members while they are here, where they will be able to examine and study the question for themselves. It presents abundant opportunities for the development of theories. The writer has had various theories about it, but should any of them become evident in this paper he warns anybody who attacks them that he may suddenly find him on his side regarding them.

To simplify the following description, the gorge has been divided into six parts, as follows:

A B, 11 500 ft. long; *B C*, about 4 000 ft.; *C R*, about 1 200 ft.; *R D*, 2 000 ft.; *E F*, 3 200 ft.; *F H*, 3 700 ft. These distances are

but roughly approximate, and obtained by scaling. The portion *A B*, beginning at the falls, is generally about 800 to 1 200 ft. wide at the water surface, has but slight descent and a rather slow current, and along its axis, as shown by the soundings, depths of 120 to 190 ft., the latter depth being toward the upper portion. This is the only portion in which soundings have been taken.

B C, at the water surface, has a width of about 400 ft., a descent of about 26 ft., and, as would be expected, a tremendous current, very much broken up and about 10 or 12 ft. higher in the middle than at the edges.

C R, at the water surface, has a width of about 600 ft., a descent of about 2 ft., current decreasing and becoming smoother at *R*.

R D, the portion known as the Whirlpool, has at the surface a length of 2 000 ft.; width, 1 100 ft. The outlet *E*, on the right-hand side, is about midway between *R* and *D*. The axis of the current from *R* approaches the right side, and while some of the water flows directly through the outlet, the greater part flows past the outlet, impinges against the shore at the right of *D*, turns to the left and circles around till nearly opposite the outlet, where, meeting the portion coming down the left side, both currents are driven toward the outlet, and, passing under the former current, come boiling up at the outlet and flows through it in a new direction at an angle of over 90° from its former direction. Beyond *D* is a ravine, down which a small brook flows and empties into the Whirlpool at *D*. *E F* has a surface width of 600 ft., a descent of 4 or 5 ft., and a considerable current.

At *F* the surface suddenly narrows to about 300 ft. in width, with an increasing current and a descent of 7 or 8 ft., to *H*, where the width becomes about 900 ft.

Throughout the whole distance the sides of the gorge are vertical at the top, and next to the Horseshoe the vertical portion extends nearly to the lower surface. Below this point the banks are vertical or overhanging, with heights of 30 to 60 ft. Below this, a slope formed of the débris from the sides, with inclinations of 35 to 45°, extends to the water's edge. The upper stratum of rock is generally 10 to 15 ft. thick, of limestone, possessing considerable strength, but flakes off slowly by exposure to the atmosphere. This is succeeded by limestone shale, blue shale, more finely stratified limestone and red sandstone, red shale and limestone strata with clay seams.

PLATE XXVI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXIX, PAPER 827.
BUCK ON NIAGARA GORGE.

The existence of the great falls is due to this arrangement of the formation. The water falling over the edge of the top stratum excavates the softer materials below, until the top stratum projects so far out that its own weight and the superincumbent water causes it to break off.

From the soundings below the falls, as well as from a study of the Genesee Falls at Rochester, where the formation is very similar, it appears that generally the fall excavates to a depth below the lower surface about equal to the height of the fall above that surface.

Judging from the generally uniform conditions existing from *A* to *B*, it is reasonable to suppose that the excavation throughout the 11 500 ft. has gone on at about the present rate. If so, it would have occupied a period of about 4 000 years. This applies only to a little over 2 miles of the 7 miles of gorge, or less than one-third of the distance.

At *B* the conditions are abruptly changed. The chasm becomes but about half as wide as at *A B*. Although no soundings can be taken, there is good reason to suppose that the depth does not exceed 80 ft. Then there is the rapid descent of the surface. One feature exists in the formation in this portion which does not occur in the former portion, in the fact that here we have a second strong stratum of rock about 12 to 14 ft. thick, located about 115 ft. below the top one, and suggesting that it may have caused the fall to be divided into two parts, the lower following the upper. This argument is also supported by the fact that immediately overlying this second strong stratum is a stratum of blue shale 50 ft. thick, which would be rapidly disintegrated by a heavy volume of water falling upon it, or if, with a fall of 115 ft., it suddenly brought up against the second smooth stratum, which would deflect a considerable portion of it laterally and violently against the shale. The excavation here would be much more rapid, and consequently make the gorge narrower.

The Whirlpool appears to indicate that there must have been a great cavity in the rock, although some writers have advanced the theory that at one time the river continued in the direction of *R D* produced, and after excavating the gorge up to about the present outlet became dammed by glacial action or some natural convulsion, which diverted the water into its present course. This may be the most reasonable theory.

The third striking feature is that at *F H*, where the great protuberance *G* juts out from the left bank, with a considerable ravine between it and the bank, and extending from the lower end about half way to the upper end.

There may have been a long, narrow island about over the highest part of this protuberance before the falls reached this part. This would divide the stream, the larger channel to the right. Such larger channel would cut more rapidly and deeper than the other one, so that by the time the smaller had cut about half way up, the larger would have reached the upper end of the island, and would then divert the water from the smaller channel to itself. The island afterwards would crumble down to its present form.

It must be constantly borne in mind that at whatever point the falls have been, the river above them has spread over a much greater width than that of the present gorge, and that the falls themselves always left the gorge narrower than we now find it, to be afterward widened by atmospheric influences.

In the remaining two miles the gorge presents some features of minor interest, but none so striking as those described.

DISCUSSION.

F. Lynwood Garrison, Assoc. M. Am. Soc. C. E.—As the length of time in which the Niagara gorge could have been eroded by the action of the falls is a subject upon which there is some difference of opinion among competent geologists, it would seem that Mr. Buck's estimate of 4 000 years as the probable period necessary to effect this excavation from the whirlpool rapids to the present site of the falls is somewhat arbitrary.

Our knowledge of geological phenomena has of late years undergone such modifications that I think it is doubtful if geologists are agreed that the formation of this gorge has been necessarily due entirely to the erosion; there seems to be some disposition to attribute at least its primary existence to a fault, crack or dislocation of the Niagara limestone and its underlying shales.

The State Geologist of New York, Professor Hall, and the famous English geologist, Lyell, both estimated the average rate of erosion by the falls at 1 ft. per year. Professor Dana considers their estimate large. Desor calculated the erosion at about 3 ft. per century. Estimating

the total length of the gorge from Queenstown to be 6 miles, at the rate of 1 ft. per year 31 000 years, and at 1 in. per year, or about $8\frac{1}{3}$ ft. per century, 380 000 years would elapse before the falls would reach their present location. Blakewell, I believe, estimates the rate of recession at 3 ft. per year. Professor Archibald Geikie considers Lyell's estimate as the more probable conjecture.

If Mr. Buck's calculation of 11 500 ft., as the distance between the falls and the whirlpool rapids is correct, and if we accept Blakewell's estimate of 3 ft. per year, Mr. Buck's calculation of 4 000 years would appear to be about right. Admitting the gorge was formed by the action of the water, which has been by no means proved, and was not due to any other cause or causes, it seems to me this estimate of 4 000 years is altogether too small. The consensus of opinion of geologists would seem to be nearer that of Lyell's estimate of 1 ft. per year, than any other ; at this rate the gorge along the line *A B* would require about 12 000 years. Professor Geikie, I believe, maintains that the entire gorge was formed by the erosive action of the falls and was not due to any dislocation, rent or fault in the rocks.

Robert Fletcher, Assoc. Am. Soc. C. E.—It may be well to call to mind some geological opinions on this subject. It is well known that Lyell's estimate of the time required to excavate the Niagara gorge exceeded 100 000 years. I have the opinion of a geologist who has made considerable study of the subject, to the effect that opinions among geologists have been much modified in recent years, and that the disposition is now to place the time very much less than that, certainly not more than 10 000 years, and with the tendency to reduce even that figure.

Joseph P. Frizell, M. Am. Soc. C. E.—I want to say a word on the gorge as the result of abrasion. It seems to me that there is a very trustworthy criterion to determine whether this gorge resulted from a natural process of abrasion such as is now going on, or was determined by a fault in the rock. The river above the falls is some 5 000 ft. wide, while the gorge is scarcely more than 1 000 ft. Now, if we assume that the river once flowed from Lake Erie to Lake Ontario, as it now flows from Lake Erie to the Falls, and that, by the natural process of abrasion, by the undercutting of the cataract and the fall of the superincumbent rock, the falls have receded to their present position, this history would be plainly written in the adjacent topography. We should find along this gorge, and on both sides of it, the banks, the deposits and the abrasions incident to the flow of a wide and swift stream. Whereas if the present course of the river had been originally determined by a fault in the rock, these indications would be wanting. I do not know whether such topographical features exist, but it seems to me that this is the true criterion for verifying or disproving the hypothesis of a fault.

Howard J. Cole, Assoc. M. Am. Soc. C. E.—It seems to me that if this gorge had been formed by the abrasion of the rock there would be some indications of it in the lake. The river ought to deposit the material accumulated from the decomposition of the rocks in a peculiar form of natural shelf soon after it enters Lake Ontario. I would like to ask Mr. Buck if he has any information about this, and whether soundings have been taken in the lake that show indications of a deposit.

L. L. Buck, M. Am. Soc. C. E.—I cannot inform anybody regarding the deposit in Lake Ontario, as I have never made any investigation there.

Mr. Cole.—It would not begin to deposit the material until it enters the still water of the lake.

Mr. Buck.—Yes; it might deposit some in the river below the mountain. Supposing the falls commenced at the mountain they would be apt to excavate a considerable basin below, both as to width and depth. The material of such excavation would be carried to the lake; then when the falls had receded to some distance, this basin would retain some of the disintegrated material.

Mr. Cole.—I have seen a somewhat similar case of a brook coming down a mountain side, carrying in suspension gravel and earthy matter scoured from its course, finally emptying into a small pond where it formed a shelf of this material and extended this shelf out until it very nearly filled the mill pond. I think the Niagara River would act on the same principal if the gorge was formed by abrasion.

Mr. Buck.—Not wishing to take too much time here that may be required on some more profitable paper, I would say that this paper was written to call the attention of the members, while on the spot, to the peculiarities of the gorge and to point out the portions where, at various times in the past, the conditions must have been different from what they are at present.

Answering the question as well as I can:

There is the heavy stratum at the top of the fall, over which the water breaks, but further inland there are some finer strata overlying the heavy one. Above the falls, in the channel, these finer strata crumble away and form the rapids as they exist above the falls. The material below the heavy stratum is of a more frail nature. As before stated, there are thin strata—some very thin. There are some very thick strata of blue shale which do not withstand the action of water and air. These fine strata and the shale are torn out by the water, assisted by the air which gets behind the falling sheet of water, until the process has excavated so far back that the weight of the projecting shelf, with the superincumbent water, becomes too great for its strength, when large masses of it are broken off and fall into the channel below. They doubtless get still further broken up in falling,

and again by succeeding pieces falling upon them. Most of these large pieces probably remain in the bottom. It is not likely that any of these large masses, or even any masses, are carried to the lake. Hence I concluded that the material, like the shale and clay, must be in sufficient proportion to the whole that, together with the very finely disintegrated stone, their removal will leave the channel in its present form; and such portions are mostly carried well out into the lake before they are precipitated.

J. T. Fanning, M. Am. Soc. C. E.—The upper Mississippi River presents an interesting example of the erosion of a river-bed at a fall. There is a gorge excavated by the Mississippi River extending from Lake Pepin about 50 miles up stream to St. Anthony Falls, in Minneapolis. When the lumbermen began building their mills, in 1855, the falls were found to be receding rapidly. The bed of the river at the falls is a firm limestone about 12 ft. in thickness, and beneath this limestone is the soft St. Peter sandstone. The fall was about 50 ft. in height, and eroded the stone below and undercut its limestone cap, leaving the limestone as a projecting shelf. The weight of the water at the fall broke off this projecting shelf, usually in widths of about 12 ft., when the process of undercutting and breaking off would be repeated. It was found in 1856 that the falls were receding by this process of undercutting and breaking, about 100 ft. per year. This limestone cap becomes thinner as it extends up stream, and about 1 500 ft. from the crest of the falls it disappears entirely, and the bed of the river from this point upwards a considerable distance is the soft sandrock. There was danger that the limestone would be soon cut entirely away, when the falls would recede at a much more rapid rate. The millers and citizens of Minneapolis made a desperate attempt to stop this undercutting and recession of the falls, and the Government finally came to their assistance and covered the falls with a sloping timber apron. This timber apron was described in a paper read before this Society by Colonel Farquhar, a member, in June, 1883.

Charles H. Snow, Assoc. M. Am. Soc. C. E. (by letter).—It should not be understood, as it may be from something said in discussion, that all hard rock resists the action of water better than all soft rock. Water acts upon rock in two ways—mechanically and chemically. In the former, hard rock may resist abrasion better than soft. In the latter, action results from some chemical in the water, as carbonic acid, or else from some substance in the rock which will oxidize on contact with water, as iron sulphide. Chemical action is, then, independent of hardness, so that soft rock may resist its influence even better than hard. The action of water on hard rock is sometimes surprisingly rapid. Lyell mentions the case of the Simeto, in Sicily, which had been dammed by lava in 1600 and which by 1850 had a new channel, in parts 200 ft. deep and 40 to 50 broad. In the same connec-

tion, I recall in Oregon a mass of hard volcanic matter 500 or 600 ft. high, a face of which had been eroded down to much below the original surface. A drift for mining purposes into the hill immediately below the trap encountered trees of considerable size, portions of which were hardly, if at all, altered from the condition in which they were when enveloped by the lava flow, so that they had to be removed by the axe. Yet other portions of the same trunks were perfectly salicified and could be removed by the sledge alone. The same tree would afford a series all the way from woody fiber to wood opal. How long it took for the 500 or 600 ft. of lava to be cut through I had no means of determining, but it was not long enough for the trees to have become entirely salicified.

A result noticed for the first time at Niagara Falls is the abrasion due to the movement of the air currents caused by cataracts. It is the spray sent off at the impact of the water and further propelled by the winds that excavated the cave under the falls.

It would be interesting to know whether the gorge further widens by the side action of the current as it flows past—an influence to which the vertical sides of cañons are usually due. Also, whether the rapids above the falls are caused by unevennesses in the rock texture, harder rock presenting a check to even wear, and thereby causing ripples or waves.

The question has arisen as to whether a bar exists at the mouth of the river. As material deposited in a swift current is sorted by the current, the only matter which would remain influenced by the current where the quiet of the lake is encountered would be small particles or pebbles, the large pieces dropping when the current begins first to be checked.

Mr. Schneider's paper on the cantilever bridge tells us that the bridge is founded on such large rocks from the hard upper strata.

Mr. Buck (by letter).—In reply to Mr. Frizell's discussion regarding the evidences of water having flowed over the surface of the rock at the sides of the gorge, it will be noticed that at various distances back from the brink of the gorge the original banks of the river still exist generally well defined. At Suspension Bridge and on the opposite side of the river the upper surface of the top stratum of rock shows abundant evidence of the water having flowed over it.

In reply to Mr. Snow's remarks about the side action of the current in the gorge below the falls, there is no appearance of erosion from this cause. The gorge does widen after the falls have passed onward. The cutting, or rather the breaking and tearing away, caused by the falling water, leaves the gorge much narrower than it afterwards becomes, and with nearly vertical or even overhanging sides. The rock, being of a nature which does not bear exposure to the atmosphere, continues to fall off, and gradually forms the slopes of débris seen on

each side. This action is especially notable each season of the year when the frost is thawing out of the banks.

It is very possible that a fissure may have existed in the vicinity of the whirlpool, and for a long time I was disposed to that view of it, from the fact that the form of the gorge at that point would suggest a three-way fissure, and that the conditions indicated a very much more rapid action from the whirlpool to a point above the railroad suspension bridge than now exists. A closer examination of the formation existing under the bridge satisfied me that, at least, the fissure theory was not necessary to prove rapid cutting, as it is much less fitted to withstand the action of the falling water than the portion nearer the present falls. Moreover, a fissure of large dimensions is generally due to an upheaval, causing the strata to dip each way from the fissure. So far as I have been able to discover, they do not so dip. At Suspension Bridge there is a slight dip, but it is in the same direction on both sides of the river, viz., easterly, and the dip appears to have been continuous across where the gorge now exists.

Finally, when any geologist advances the theory that Niagara Falls have been employed 100 000 years in cutting the present gorge, it is safe to say that either he has never examined the formation closely, or that he has no conception of the prodigious effect of such a vast body of water falling 160 ft. One passage through the Cave of the Winds, where it needs a strong man to withstand the air-pressure caused by a comparatively thin stream of water, will give one some idea of what it must be behind the Horseshoe Fall, where the sheet of water is about 30 ft. thick, if not even more than that. The motion of the air alone would be very destructive, and when laden with water is still greater.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

728.

(Vol. XXXII.—August, 1894.)

THE PULP MILL OF THE CLIFF PAPER COMPANY OF NIAGARA FALLS, N. Y.

By WALLACE C. JOHNSON, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

Previous to the completion of the tunnel and canal of the Niagara Power Company, the only water power available at Niagara Falls was that furnished by the Niagara Falls Hydraulic Power and Manufacturing Company.

The water used by this company is drawn from the river at a point above the head of the rapids about a mile above the falls, and conveyed through the city to a point about one-half mile below the falls by a canal 4 400 ft. long. The canal discharges into a basin running nearly parallel with the edge of the high bank and about 350 ft. from it. From this basin water is drawn to supply about 10 000 H. P. to the various mills shown in Fig. 1.

The universal method of using this water, previous to the construction of the plant under consideration, had been to sink a shaft at some point between the basin and the edge of the high bank to a depth of

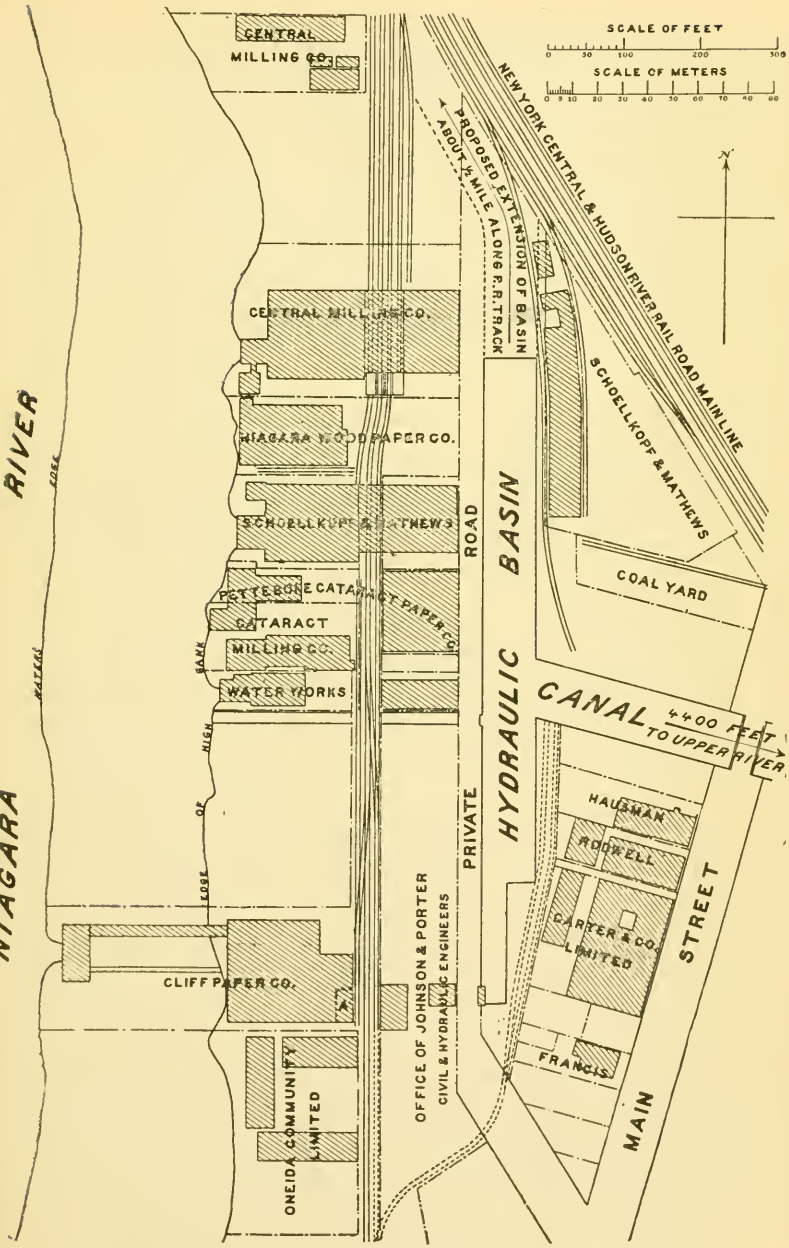

SCALE OF FEET
0 30 100 200 300
SCALE OF METERS
0 5 10 20 30 40 50 60 70 80 90
N
NEW YORK CENTRAL & HUDSON RIVER RAIL ROAD MAIN LINE
PROPOSED EXTENSION OF BASIN
ABOUT ½ MILE ALONG R.R. TRACK
CENTRAL MILLING CO.
CENTRAL MILLING CO.
NIAGARA WOOD PAPER CO.
SCHOELLKOPF & MATHEWS
SCHOELLKOPF & MATHEWS
COAL YARD
PETTEBONE CATARACT PAPER CO.
CATARACT MILLING CO.
WATER WORKS
ROAD
HYDRAULIC BASIN
CANAL
4400 FEET TO UPPER RIVER
PRIVATE
HAUSMAN
ROBRELL
CARTER & CO. LIMITED
FRANCIS
MAIN STREET
OFFICE OF JOHNSON & PORTER CIVIL & HYDRAULIC ENGINEERS
CLIFF PAPER CO.
ONEIDA COMMUNITY LIMITED
NIAGARA RIVER
HIGH WATER MARK
LOW WATER MARK

FIG. 1.

from 50 to 100 ft., to place in the bottom of this shaft vertical turbine wheels, and discharge the water from the bottom of the pits upon the face of the bank, as shown in Plate XXVIII, which is from a photograph of the bank, showing the mills and the water discharged from the various pits.

The reason for this wasteful use of the water lay in the fact that at the time these various mill sites were sold, the power company did not own the sloping bank. The original deeds to the builders of the canal only conveyed the title to the land to the edge of the high bank and granted the right to excavate to a depth of 100 ft. and discharge the tail-water over the sloping bank to the river.

To all of the mills fronting on the hydraulic basin north of the water works, shown on Fig. 1, the right to draw water from the basin had been sold or leased.

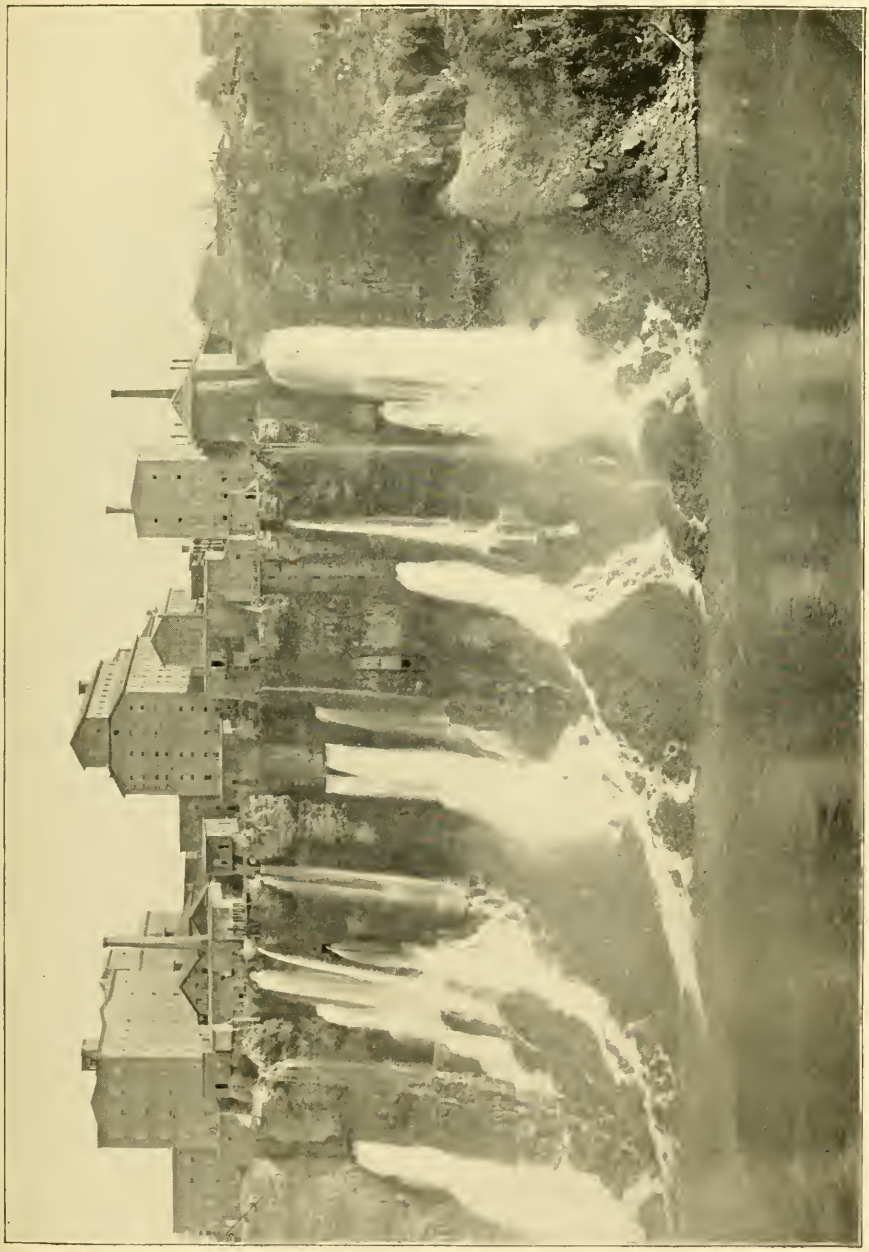
In 1881 the Niagara Falls Hydraulic Power and Manufacturing Company sunk a shaft for a wheel pit at the point *A* (Fig. 1), 20 x 40 ft., and about 80 ft. deep, and drove a tunnel from the bottom of the shaft to the face of the bank for the discharge of the tail-water.

Three turbine wheels have been placed in the bottom of this shaft capable of developing about 1 700 H. P. From these wheels power is delivered into the factories of the Cliff Paper Mill above the bank, the Oneida Community, Limited, and all the mills fronting on Main Street, as shown in Fig. 1. This pit, wheels and turbines are shown in section on Fig. 2.

Until within the past year all the water discharged by these wheels was poured out from the mouth of the tunnel at an elevation of about 125 ft. above the water in the lower river.

The writer entered the service of the Niagara Falls Hydraulic Power and Manufacturing Company, as engineer, in 1886, and soon after that time the company acquired the lands on the sloping bank between the face of the cliff and the water of the lower river, giving it the right to utilize the full available head of about 215 ft.

The company owns a strip of land 100 ft. wide from Port Bay, the point where the water is taken into the canal through the city to their lands where the mills are located. The canal, as originally excavated in this strip, was only about 35 ft. wide and 8 ft. deep. The capacity of this canal was about 13 000 H. P. if used under the full head of 210 ft. As the wheels had been put in, only about 6 000 H.P. were



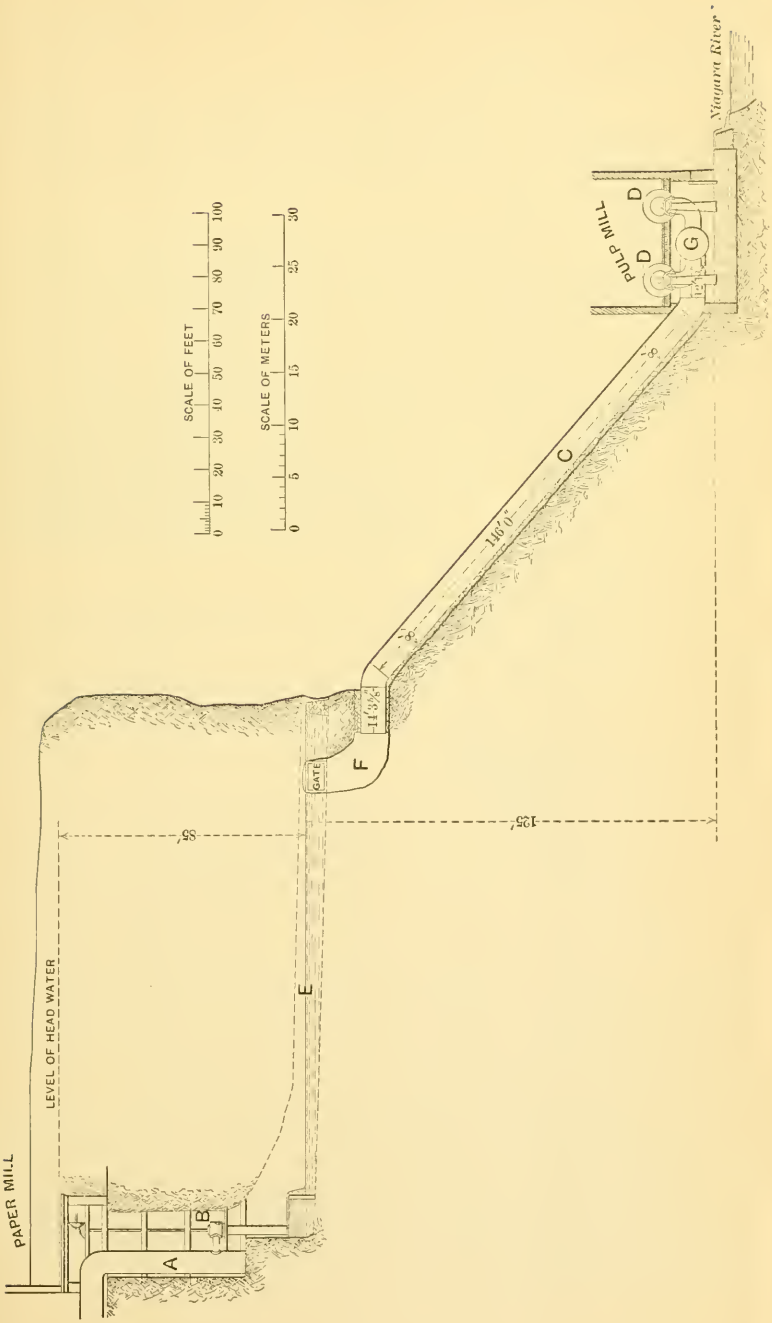

PAPER MILL
LEVEL OF HEAD WATER
A
B
E
GATE
F
14.5%
88'
125'
C
146'0"
8"
PULP MILL
D
D
G
Niagara River
SCALE OF FEET
0 10 20 30 40 50 60 70 80 90 100
SCALE OF METERS
0 5 10 15 20 25 30

FIG. 2.

obtained from the full capacity of the canal. This was all used by the various mills shown on Fig. 1.

In 1892 the company commenced the enlargement of its canal by excavating an additional 35 ft. in width to a depth of 14 ft. This enlargement, which is now practically completed, gives a total capacity of upwards of 50 000 H. P.

In the spring of 1892, the Cliff Paper Company became desirous of increasing their plant by adding a wood pulp mill, to use about 2 500 H.P. They leased sufficient water from the Niagara Falls Hydraulic Power and Manufacturing Company, and, not desiring to wait for the enlargement of the canal to be completed, they agreed to take it from the tunnel through which water was discharged from their pit, and the writer was called upon to design the plant.

For the purpose of getting the machinery requiring the largest power near to the wheels, it was decided to build a mill on the lower bank near the water's edge, and to place the pulp-making machinery in it, preparing the wood on the top of the bank, lowering it down ready for grinding and elevating the product.

The general design and working of the plant is shown in Plate XXIX. In the room *A* is placed the machinery for sawing the wood to the proper length and removing the bark. The logs thus prepared are placed upon a chain conveyor at the point *B*, carried down the incline into the grinding-room floor, in the mill below. The wood is ground on this floor and mixed with water and flows into a tank in the basement; from this point it is elevated by pumps to a tank in the roof, and flows from it on to the wet machines, where part of the water is removed, leaving it in the form of a wet, paper-like substance; from the wet machine it drops on to another conveyor (*C*, Plates XXX and XXXI) and is carried to the returning side of the same conveyor which brought down the wood, then carried up the incline to the second story of the mill above the bank, where it is dropped on to the belt conveyor *C*, and from there to another, *D*, running at right angles with the direction of the first conveyors, which carries it to the beating engines.

To divert the stream of water flowing through the tunnel (*E*, Fig. 2), and confine it for use in the new mill, a short tunnel (*F*, Fig. 2) was driven into the face of the bank at a point about 20 ft. below and 12 ft. to the left of the mouth of the old tunnel. The relative position of the two openings into the face of the bank is well shown on Plate

PLATE XXIX.
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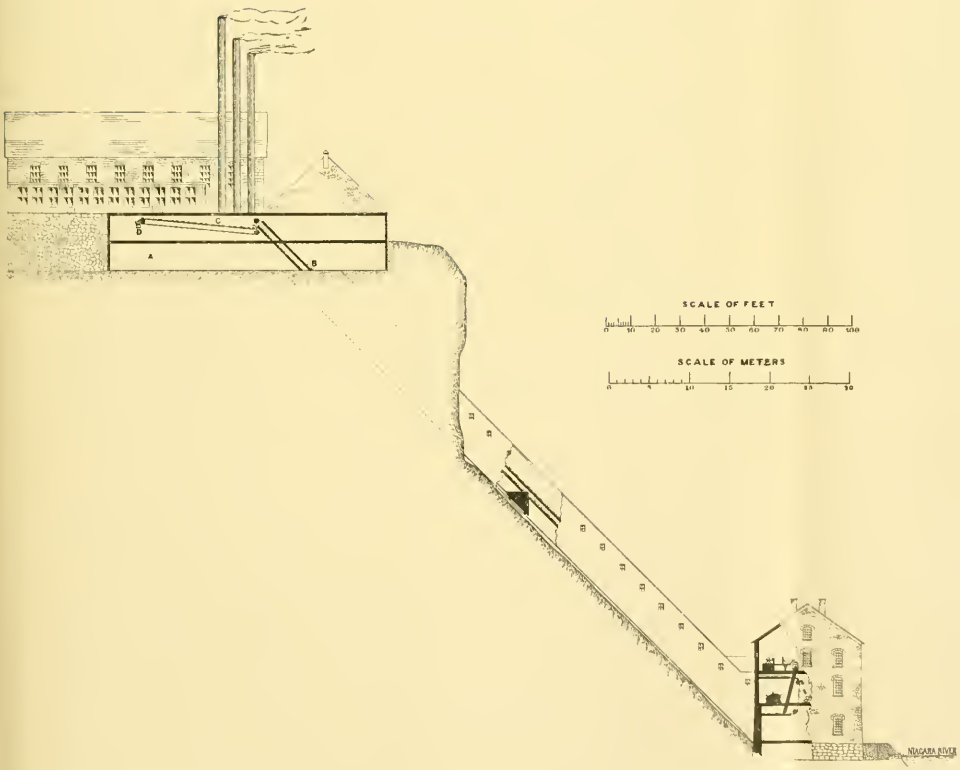
JOHNSON ON PULP MILL AT NIAGARA FALLS.



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XXXII, which is from a photograph taken during construction. The plan of the tunnel and its connection with the old tunnel is shown on Plate XXXIII.

From the mouth of the new tunnel, an iron pipe 8 ft. in diameter (*C*, Fig. 2), was laid along the slope of the bank connecting with the tube *G* (Fig. 2), 10 ft. in diameter, in the basement of the lower mill. From this tube the water is brought to the wheels on the first floor. Provision is made for the discharge of water into the tunnel direct from the canal in case the discharge from the wheels does not furnish a sufficient supply.

Owing to the contracted channel of the river below the mill there is an extreme fluctuation in the water below of about 30 ft. and it is liable to sudden changes. On this account the first floor, on which the wheels are placed, is set about 16 ft. above the ordinary level of the water in the river, which is above the highest recorded rise, the remaining part of the head being obtained by the use of draft tubes.

Work was commenced on this plant about May 1st, 1892. The first thing done was to trim off all of the rock on the face of the bank which appeared to be in danger of falling. Then a notch was excavated in the bank 12 ft. wide and to the depth of the dotted line Plate XXIX), and the tunnel was driven and the gate put in at its head.

During the time that the work was in progress the flow from the (old tunnel, amounting to about 130 cu. ft. per second, could be stopped only on Sundays. This water was carried past the opening in a temporary flume, which it was afterward found necessary to extend down the slope of the bank for about 120 ft. (as shown on Plate XXXII) to get rid of the spray caused by the water tumbling down over the slope, which interfered with the work on the mill below.

The opening into the old tunnel is closed by a gate and protected by a rack shown in detail on Fig 3. The gate is operated by extending the shaft *A* along the roof of the tunnel to a hand wheel, near the point *B* (Fig. 2). The rock taken out from the tunnel and the notch in the bank was thrown down upon the slope on top of the débris which had been accumulating there for ages.

The next step was to clear the site for the building and to remove the loose material which might slide down. As the broken and disintegrated rock which had fallen from the cliff at various times lay at the "angle of repose," this clearing amounted practically to removing

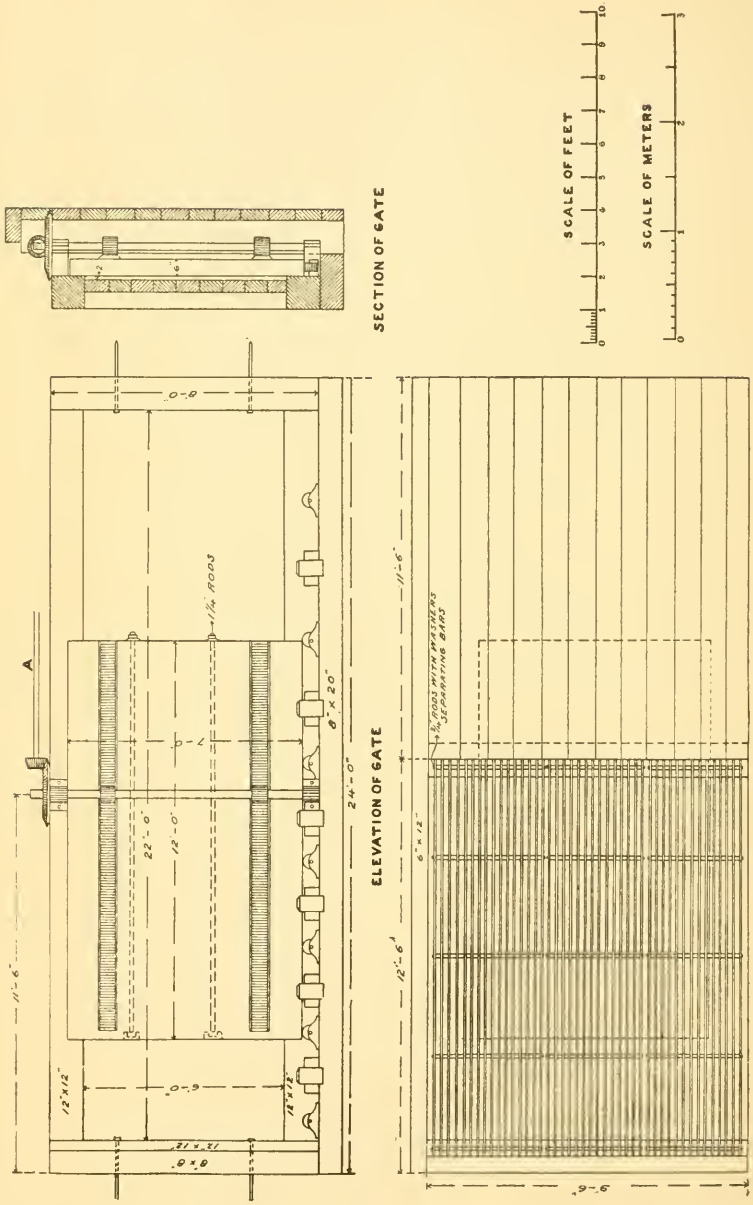
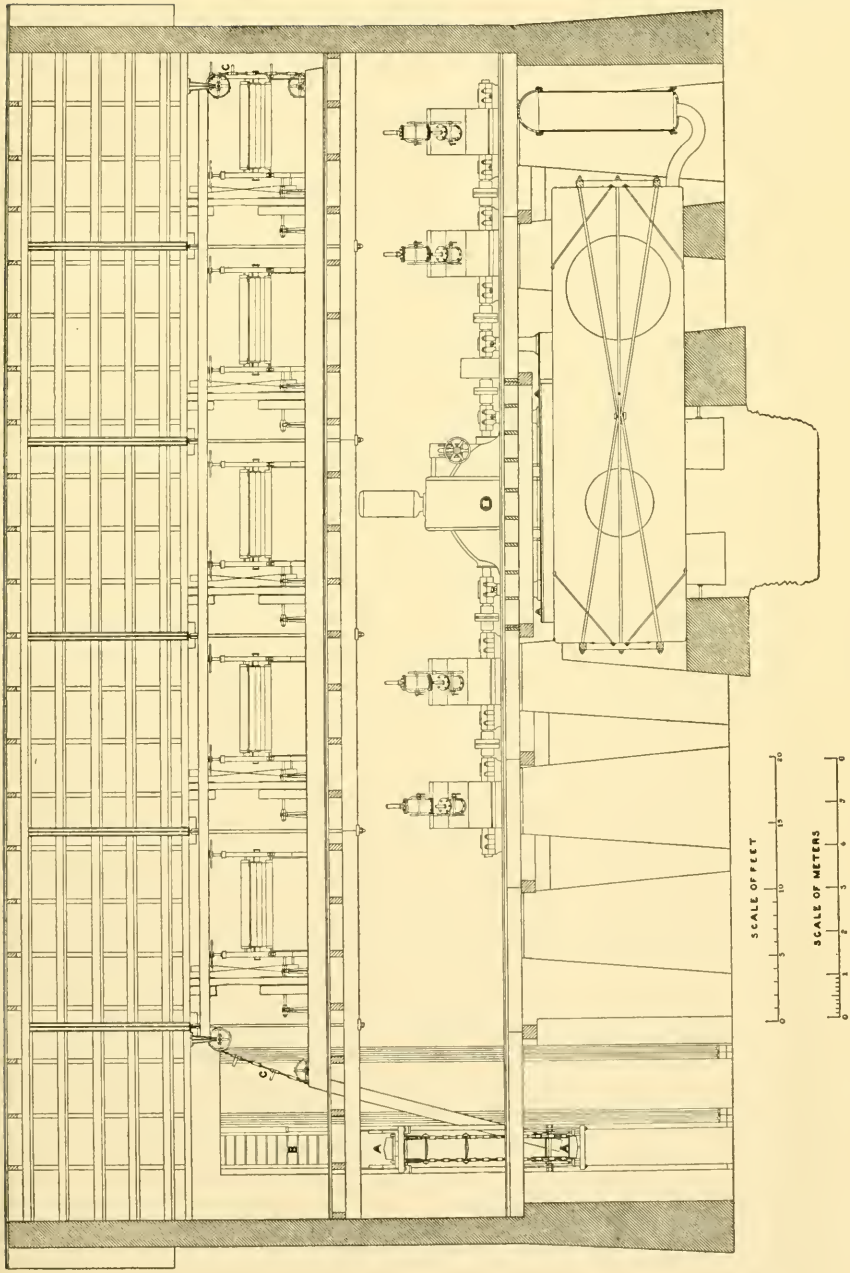

SECTION OF GATE
SCALE OF FEET
SCALE OF METERS
ELEVATION OF GATE
ELEVATION OF RACK
A
1¼" RODS
8" × 20"
24'-0"
22'-0"
12'-0"
11'-6"
12"×12"
14"×12"
21"×21"
8"×8"
9'-6"
6"×12"
12'-6"

FIG. 3.

PLATE XXX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 728.
JOHNSON ON PULP MILL AT NIAGARA FALLS.



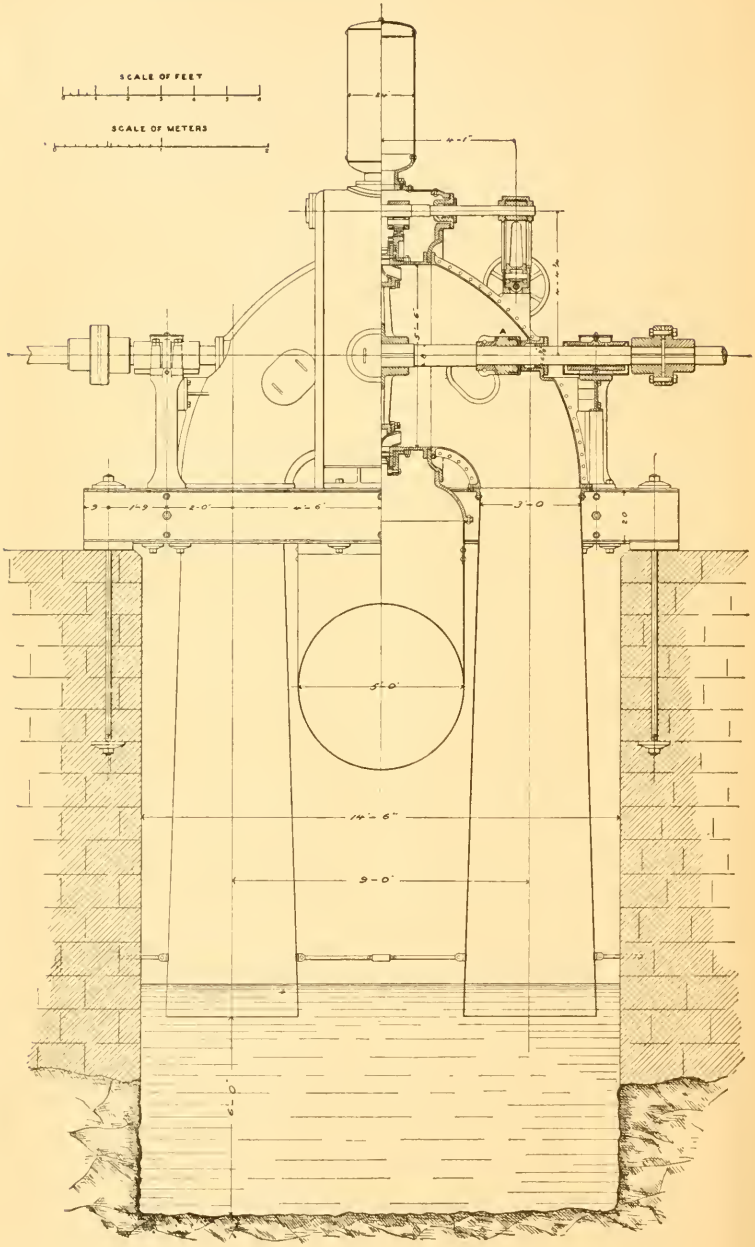
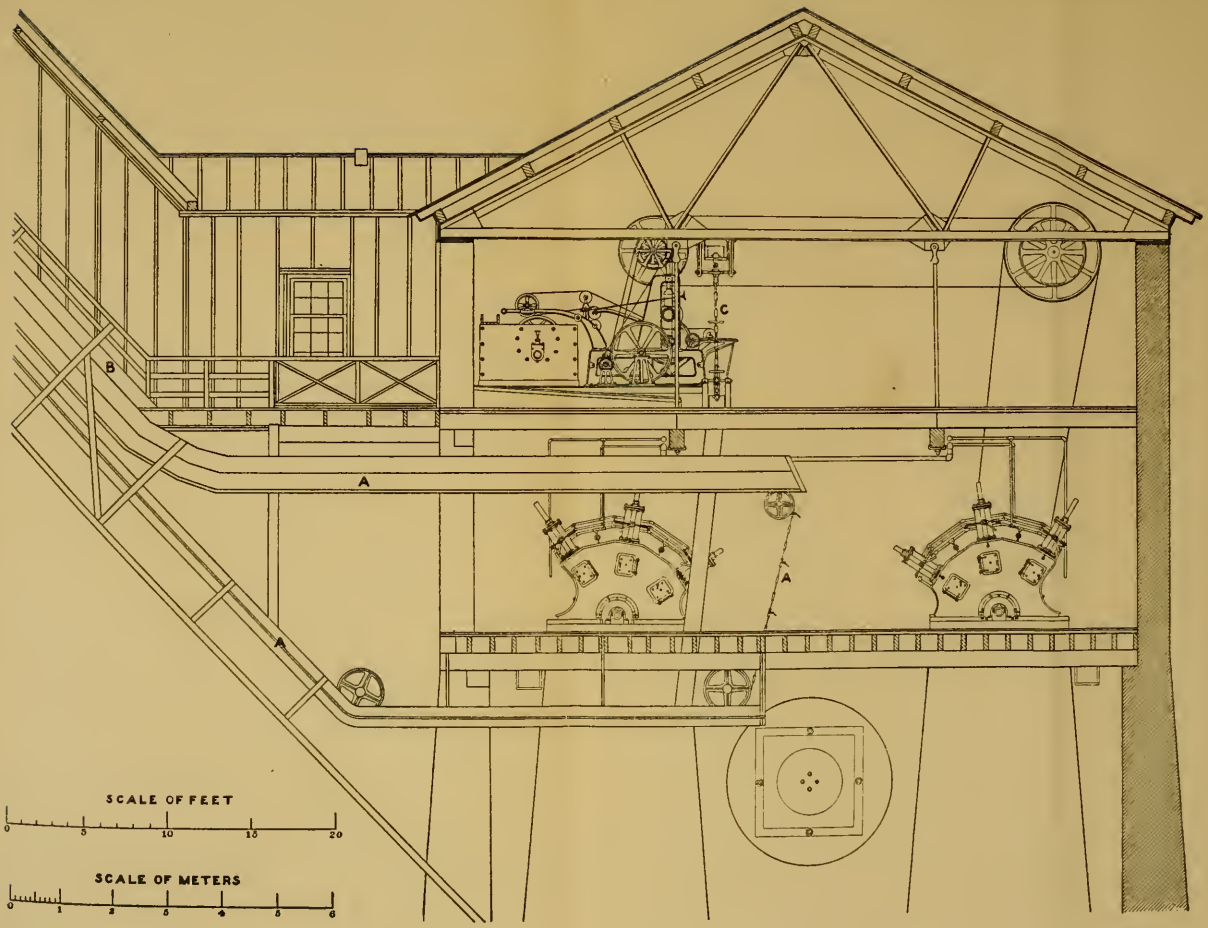


FIG. 4.


B
A
A
A
C
SCALE OF FEET
0
5
10
15
20
SCALE OF METERS
0
1
2
3
4
5
6

by a wooden frame on the outside, through which four rods 1½ ins. in diameter were passed from end to end of the tube and gathered together in a bunch at the center, as shown in Plate XXX. The upper portion of the 8-ft. tube was constructed of $\frac{5}{16}$-in. boiler steel, single riveted. This tube was made in sections about 15 ft. in length at the shops and lowered down and set in place, and the connecting seams riveted on the site.

For the handling of this and other materials a steam derrick with a 75-ft. boom was erected on top of the bank, shown in Plate XXXII. Materials were lifted from the ground near the edge of the bank, the boom swung around square with it, the load lowered on to the inclined skidway below, and, still held by the derrick, were slid down to the level of the mill, where they were picked up by another derrick and swung into place.

The mill was closed in and the tubes placed in position, so that the interior work on the mill was carried on during the winter. The construction of the incline was delayed somewhat on account of the severity of the weather.

The interior arrangement of the mill is shown on Plates XXX and XXXI. It is two stories high above the basement, and the inside dimensions are 40 x 88 ft. The walls are built of stone quarried on the site as before described, laid in Union cement mortar. The basement walls are 7 ft. thick at the base, battered on the outside to 3 ft. at the level of the first floor to resist the pressure of the loose material outside. Above the first floor they are 2 ft. thick.

The roof and second floor are supported by steel trusses calculated to support a load of 40 lbs. per square foot on the roof and 200 lbs. on the floor.

All the machines on the first or grinding-room floor are supported on independent stone foundations built up from the solid rock.

This mill is connected with the buildings on the top of the bank by a building 10 ft. wide on the inside and 26 ft. high, constructed along the slope of the bank to the face of the cliff, and from there through the notch blasted out to receive it to the mill above.

Three feet in width of this inclined building is occupied by the conveyor for handling the wood and the pulp before described and shown at *A* (Plates XXX and XXXI). Directly over the conveyor are the stairs *B*, and underneath is a line of 6-in. pipe bringing water directly

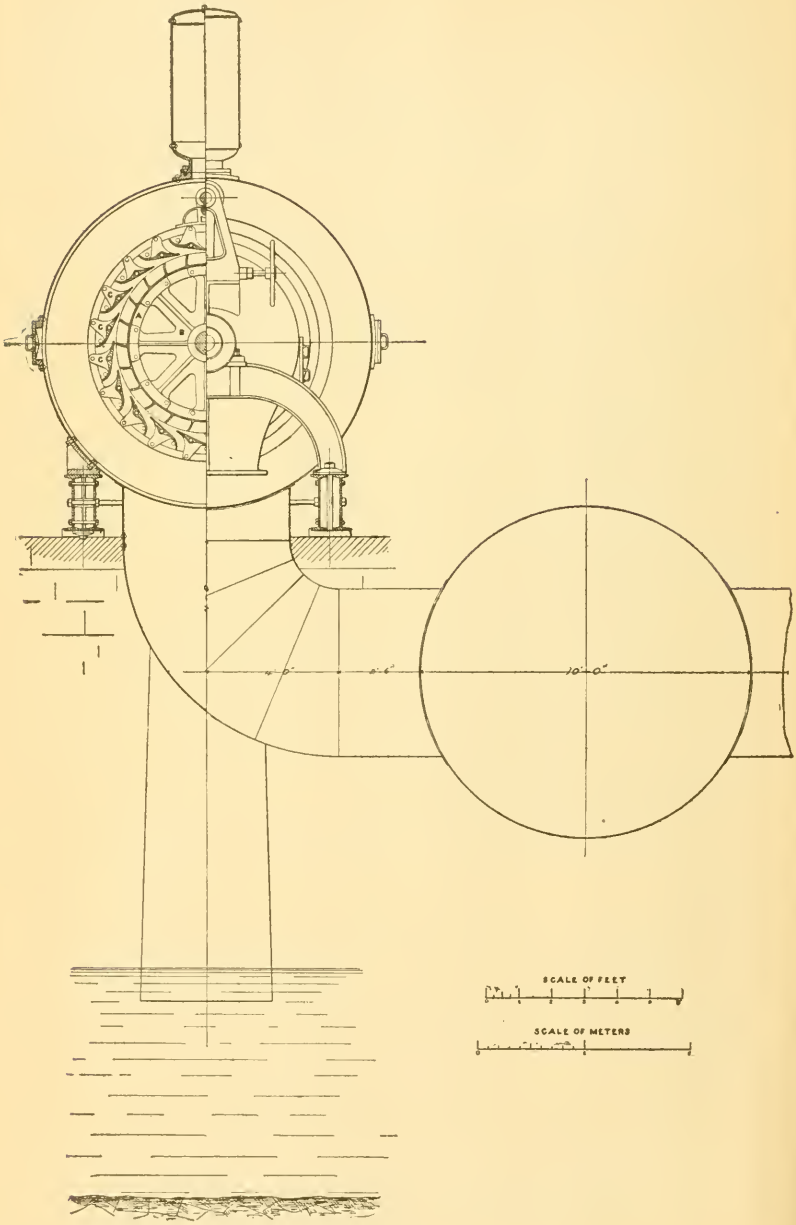
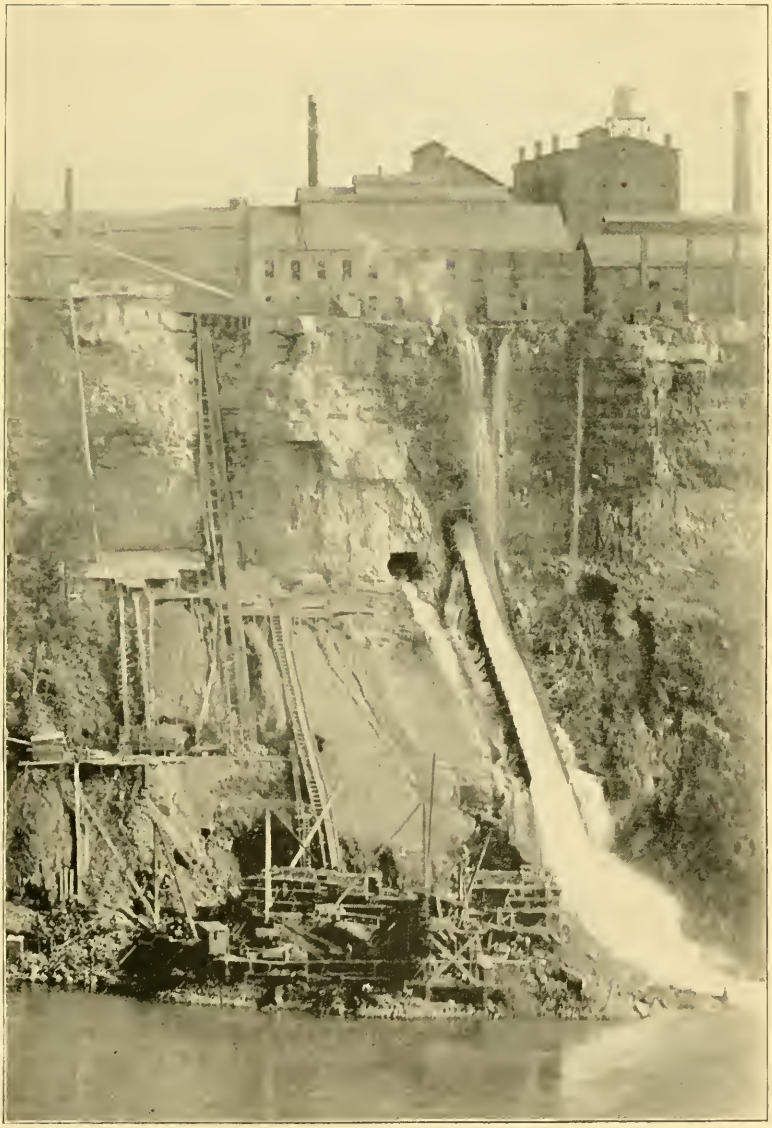


FIG. 5.



Under these specifications a contract for the construction of one wheel was let to James Leffel & Company, of Springfield, O., with the option of taking a second wheel if the first proved satisfactory.

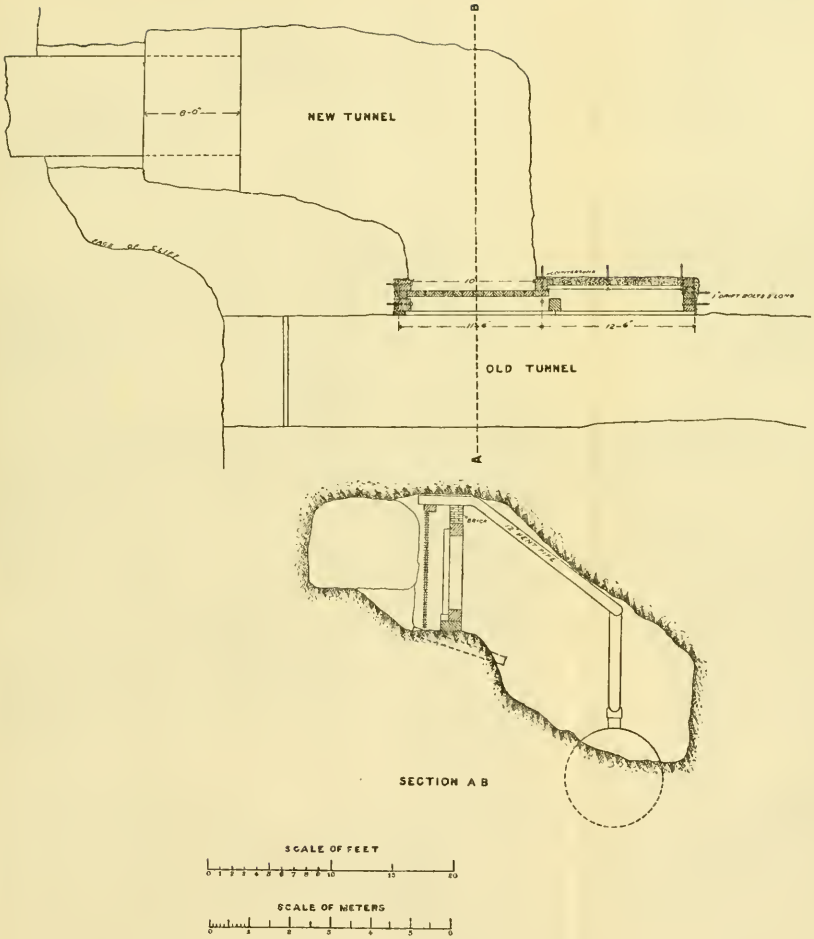
The wheels were designed by Mr. A. F. Sparks, engineer for James Leffel & Company.

The wheel runners are 66 ins. in diameter. The bucket rings *A* (Fig. 5) are made of a special quality of bronze. These rings are fitted to a heavy cast-iron center *B* (Fig. 5) with steel bolts; each ring supplied with 24 buckets, with the discharge opposite each other. The wheel runner is fitted substantially with keys to the wheel shaft, which is made of hammered wrought iron, finished diameter through bearings $6\frac{7}{8}$ ins., with a total length from center to center of couplings of 17 ft. In order to prevent the wheel shaft from shifting endwise, suitable adjustable collar bearings are located on it, immediately on the inside of the elbow *A* (Fig. 4).

Surrounding the outside of the wheel runner are wheel cylinders, supplied with 20 gates *C* (Fig. 5). These gates are made of cast steel, and designed to be as nearly balanced at all points of the gate opening as possible. They are mounted on steel gate bolts attached to wheel cylinders. Each gate is supplied with two side-rack arms which arms are attached loosely to the two side-rack rings. These rings are mounted on the wheel cylinders, and are operated simultaneously by the movement of the gate shaft connecting to them with roller rings made of cast steel. The gate shaft is made of hammered wrought iron, passing through bronze stuffing-boxes in the sides of the cylindrical case. One end of this gate shaft is operated by a suitable lever, with bronze nut, steel screw and hand wheel for same, carried in the heavy frame, mounted on one of the elbows.

This work is contained in a cylindrical case 10 ft. diameter, by 4 ft. wide. The heads are made of heavy cast iron, with $\frac{3}{8}$-in. steel shell solidly riveted to them. On the top of the case is a large air chamber to assist in equalizing any irregularities in the flow of the water to the wheel. This air chamber is supplied with an air pump and glass water gauge, so that it can be cleared properly and filled with air when necessary. The case is also fitted with manholes and plates.

On each side of the case elbows are fitted, which are made of cast iron, being split through the center and bolted together, and where the wheel shaft passes through the elbows are stuffing-boxes with bronze glands. Each elbow is fitted with manholes and plates.


B
NEW TUNNEL
8'-0"
CASE OF SLUICE
CONCRETE
10"
1" DRIFT BOLTS 5' LONG
11'-6"
12'-6"
OLD TUNNEL
A
BRICK
18" VENTILATOR
SECTION A B
SCALE OF FEET
0 1 2 3 4 5 6 7 8 9 10 15 20
SCALE OF METERS
0 1 2 3 4 5 6

On the discharge end of the elbows are fitted draft tubes which are each 18 ft. long, made of ¼-in. steel, thoroughly riveted and caulked throughout. These draft tubes are substantially anchored to the foundation walls to prevent breaks or leakage by any movement. The wheel shafts, after passing through the elbows, are carried in heavy flat bearings, each 24 ins. long, lined with anti-friction metal, bored to fit the shaft, and supplied with ring oiling attachments, with large capacity of oil chambers at each end and on bottom sides of the bearings. These bearings are mounted on heavy cast-iron bridge trees, and are supplied with suitable bolts and adjusting screws, making a distance of 4 ft. from the center of the wheel shaft down to the top of the steel beams.

The work is mounted on four heavy 20-in. steel beams, of suitable strength and proportion for spanning the foundation walls, which are 14 ft. 6 ins. in the clear. The maximum fiber strain in the beams, due to the weight of the wheel and case when filled with water, was fixed by the specifications at 9 000 lbs. These beams are secured to the foundations by foundation bolts and anchors. Every precaution was taken in the selection of all materials for these wheels, and extra care exercised in the workmanship throughout.

By this design of the wheel, the water is brought to the wheel runner through one set of gates, each set of buckets handling one-half the water, discharging opposite and parallel with the wheel shaft, thus preventing any heavy or undue thrust on the wheel shafts.

The general arrangement is such that when necessary an examination can be given the inside of the cylindrical case containing the wheel case and the operating mechanism for it, also the inside of the discharge elbows containing the collar bearings, shaft and the discharge of the wheel runner buckets.

The first wheel, driving four grinders, was started and the manufacture of pulp commenced March 13th, 1893, and has run 144 hours per week since that date without any stoppage for repairs requiring more than a few hours.

On May 20th, 1893, a test was made to ascertain whether the wheel came up to the requirements of the specifications.

The wall across the outlet to the tail-race was built with a view to setting a sharp-edged weir on it. An oak timber was set into the top inner corner, to which a 3-in. oak plank with the top edge beveled off on the outer side was securely fastened with lag screws.

Timbers had been set into the masonry forming the sides of the tail-race, and a space about 8 ft. above and below the weir was sheathed with planed and matched pine boards, making a weir without end contractions. Close along the back of the weir 1-in. iron pipe was run, perforated with holes to admit air under the sheet.

A 2-in. iron pipe was run through the wall leading the water from a point about 10-ft. in front of the weir to a tank in which the hook gauge was placed.

The penstock pipe was tapped at a point near the tunnel, and an iron pipe was led over against the side of the incline building and up the side of the building to a point above the level of the head water, and topped out with a glass tube so that the elevation of the head water could be read off a gauge graduated to feet and tenths placed alongside the glass tube. The elevation of the zero of the hook gauge was carefully taken, and the length and elevation of the weir were carefully ascertained.

The experiment was continued for three hours. An observer was stationed at the head gauge and another at the hook gauge and simultaneous readings taken every five minutes. From the readings of the two gauges, the head acting on the wheel and the quantity of water discharged were calculated. The writer observed the speed of the wheels and saw that the weight of the pulp made was ascertained and recorded.

The result of the experiment showed that 2.085 tons of pulp were made during the three hours, equal to 16.678 tons per day. The quantity of water discharged was equal to 109.338 cu. ft. per second, reduced to a head of 125 ft., equal to 6.558 cu. ft. per second per ton of pulp per day.

When the result of this test was reported, the wheel and machinery for the balance of the plant were at once ordered.

The second wheel was started December 15th, and has been running since and doing as good work as the first.

The excavating of the notch for the incline and the driving of the tunnel was done by contract. The balance of the work was done by day labor, under the immediate charge of Mr. C. H. Turver as superintendent, and much credit is due to him for good workmanship under many difficulties.

Plate XXXIV shows the mill completed, including the incline and the mills on top of the bank.

PLATE XXXIV.
TRANS. AM. SOC. CIV. ENGRS.
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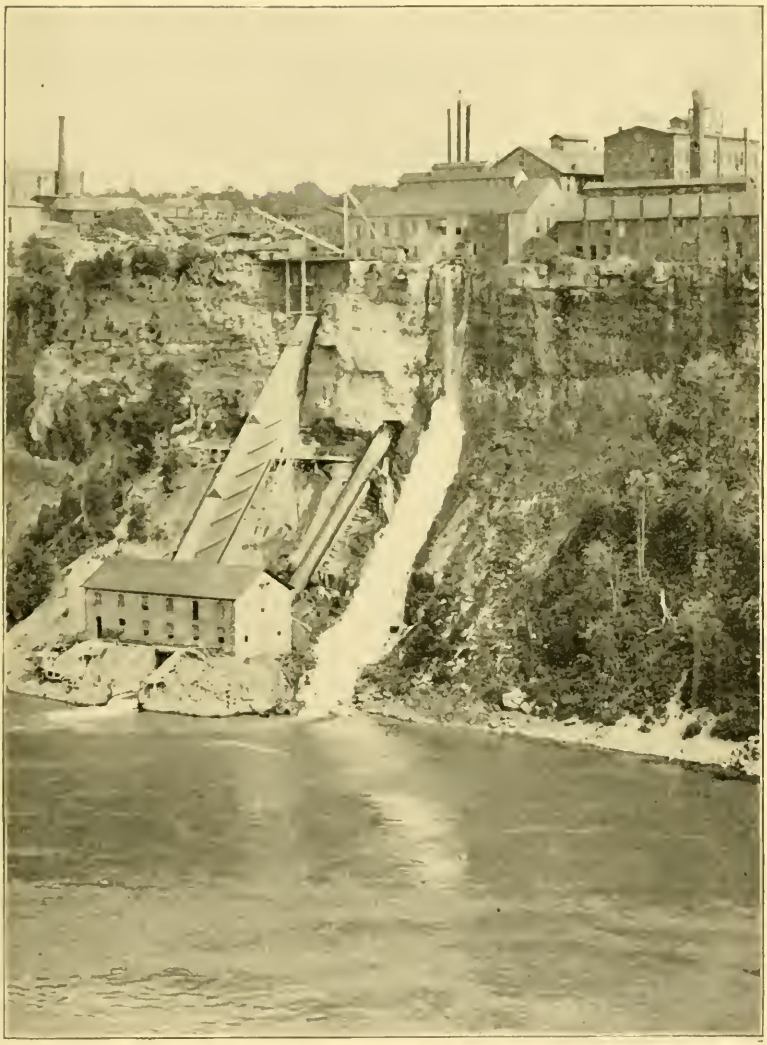
JOHNSON ON PULP MILL AT NIAGARA FALLS.



DISCUSSION.

Clemens Herschel, M. Am. Soc. C. E.—I had great pleasure yesterday in reading a paper by two young engineers, some features of which were similar to those of this paper, and I should be false to my sense of duty if I did not say something about the paper just read. We see here, as we did in that of yesterday, what I feel is a gratifying indication of the habits of the rising school of engineers, of engineers who go about testing, and putting in figures the results of their work. I do not know that I ever saw before the product of a mill reduced to the number of cubic feet that were expended in producing it. You will observe the specifications were drawn in that way. Here is a plan which, taken as a whole, consists of a great many parts, a mill on top of the bank, another below the bank, water-wheels, machinery to make pulp, etc.; but the object of the whole plant and all its expenditure is simply to make pulp for paper, and the thing to do it with is water; so much pulp to be produced, and so much water to be expended in doing it. Those were the specifications, and as you will observe from the tests, the specifications were more than complied with. As I said before, I would not be doing right if I did not express my own pleasure in the paper read, and I trust that I speak for the convention also.

J. T. Fanning, M. Am. Soc. C. E.—In relation to this method of determining the amount of power required for the unit of product of a given mill, I might mention that we have made measures of the water-power at some of the Minneapolis mills for a similar purpose. For instance, I placed a weir in the tail-race of the Pillsbury A Mill, the largest flouring mill in the country, and recorded the flow over the weir at least three times each day for a continuous period of six months. I had also the record of the daily product in barrels of flour of this mill for the same period of time, and thus had the information of the mean amount of power and the quantity of water under the given head that was required per barrel for the manufacture of flour in that mill.

The power used by five saw mills at Minneapolis was measured in a similar way throughout an entire sawing season, and the record made of the daily product in M feet of lumber of each mill.

The flouring and saw mills thus became meters indicating by the amount of their products the mean quantities of power and mean quantities of water, under the given heads, used in each unit of manufacture of their products.

W. C. Johnson, M. Am. Soc. C. E. (by letter).—In line with the remarks of Mr. Fanning I will say that, as engineer for the Niagara Falls Hydraulic Power and Manufacturing Company, I keep a record

of the quantity of water used by each mill. To ascertain this quantity, I make use of the wheel as a meter. Having once ascertained, by means of weir or other measurements, the discharge of the wheel at several different gate openings and under a known head, then by taking a daily record of the gate opening and the head acting on the wheel, the amount of water used can be readily computed.

With this end in view, a measurement of the water discharged at different openings of the gate by the wheel last put in was recently made. This wheel was made with a slightly larger gate opening than the first one. The discharge reduced to a head of 125 ft. was found to be 116.293 cu. ft. per second at full gate, 91.085 cu. ft. per second at three-quarter gate, 57.306 cu. ft. per second at one-half gate, 25.272 cu. ft. per second at one-quarter gate.

Gauges have been put on the wheels by which the proportional gate-opening can be read to hundredths, and other gauges by which the elevation of the head and tail-water can be read.

This furnishes the data by which the discharge of the wheels at any opening of the gate and at any head may be calculated.

A daily record is kept of the quantity of water used, and the Cliff Paper Company has a record of pulp made so that a computation of the water used, as compared with the pulp manufactured, may be made at any time.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

729.

(Vol. XXXII.—September, 1894.)

REMOVAL OF ROCK 40 FT. BELOW SURFACE OF WATER, NORTH RIVER, N. Y.

By JOHN A. BENSEL, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

The work, of which this is a description, consisted in the removal of about 2 000 cu. yds. of rock in the vicinity of Pier No. 14 (new), N. R., by the Department of Docks, City of New York.

The work was necessitated by an alteration in the use to which the pier was to be put. The pier having originally been built and completed, with the dimensions of 720 ft. in length and 75 ft. in width, and as for about the outer one-third of the length of this pier the bed rock rose to a grade at its highest of about 27 ft. below mean low water, and there being little or no mud overlying this rock, the construction necessitated the placing of rip-rap on this portion of the pier site.

The rip-rap was placed to a grade of 15 ft. below mean low water, except at the sides of the pier, where it was sloped to a grade of 20 ft. below mean low water. The location of the reefs removed is shown on Fig. 1.

This pier having been intended to be used for railroad purposes, the mud had been dredged to the usual depth of 25 ft. below mean low water in the slips north and south of the pier. After the pier had been completed, however, it was leased to the new American Line Steamship Company, in whose fleet are the steamships *Paris* and *New York*, and these ships drawing a maximum of 29 ft., it became necessary to make a greater depth of water along each side of the pier, the pier being also widened by the addition of 50 ft. along the entire length on the south side.

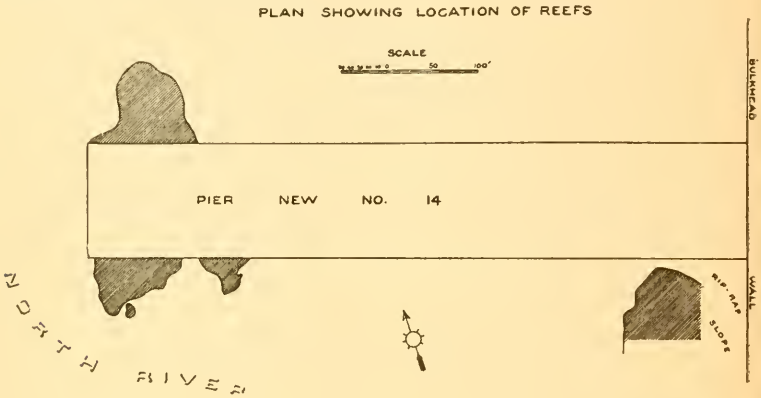


Fig. 1.

The American Line officials requested that the depth be made 35 ft. below mean low water.

The relation between the midship section of the steamships *Paris* and *New York*, with their greatest draught and the lowest recorded tide, is shown in Plate XXXV.

As the mean rise and fall of the tide at the location in question is about 5 ft., the operation of making a grade of 35 ft. below mean low water necessitated the use of appliances that would operate and do this work in 40 ft. of water, and also accommodate themselves to the rise and fall of the tide while in operation.

Operations were commenced under contract on July 25th, 1892, and were completed by the Department of Docks on September 30th, 1893. During this entire period the plant used by the Department was found efficient during all kinds of weather, even in spite of the North River ice, which was more than usually heavy during the winter of 1892–93.

PLATE XXXV.
TRANS. AM. SOC. CIV. ENGRS.
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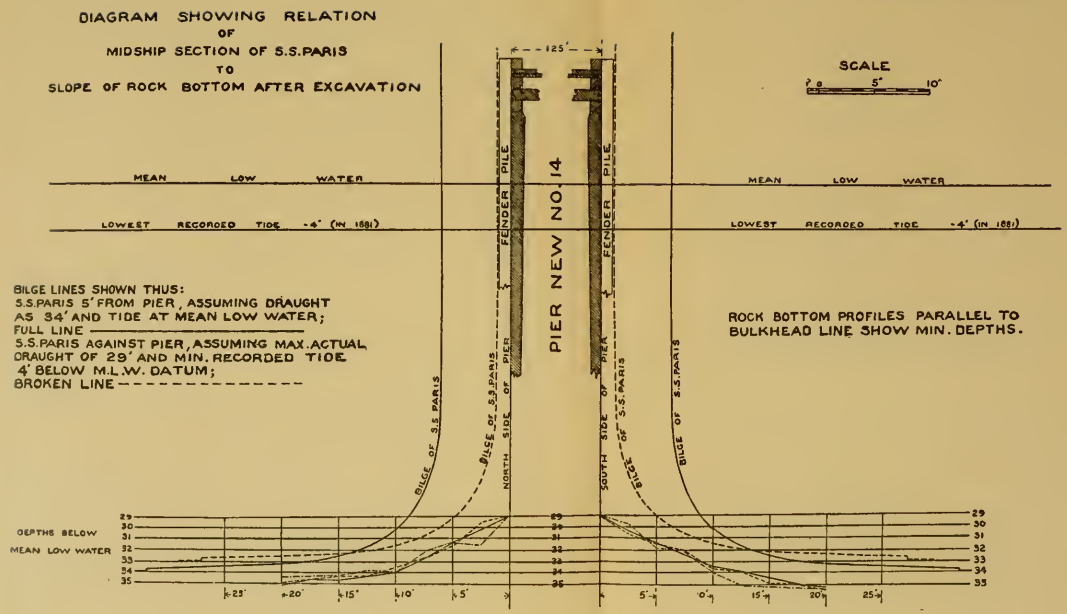
BENSEL ON SUBMARINE ROCK EXCAVATION.



There were only three days when ice absolutely prevented the continuance of operations.

The first intention as regards part of this work was to have it done by contract; and the reef south of the outer end of the pier (see Fig. 2), being the one discovered first, was let, after asking for prices, to E. R. Lowe, a submarine contractor and wrecker, at a lump sum price which amounted to about $25 per cubic yard of rock (measured in place). Work was commenced under this contract on July 25th, 1892. The plant the contractor used consisted of two platforms which had not

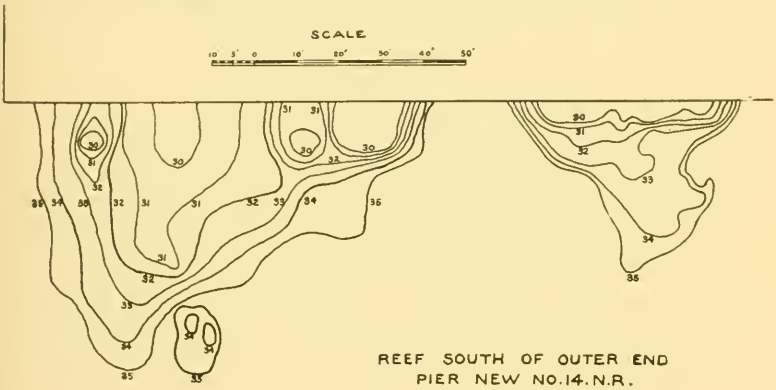


Fig. 2.

been built expressly for this piece of work, but had been used previously in the removal of rock, to a depth of 15 ft. below low water. The platforms were built with loose decks, carried on 3 x 10-in. beams, spaced about 3-ft. centers, and were in size about 18 x 20 ft. When floating on their pontoons, the corners of the platforms overhung the corners of the pontoons, and at each were boxes braced with knees to the two side timbers of the platforms. Through these open boxes passed 8 x 8-in. yellow-pine spuds 55 ft. in length, forming the standards or legs of the platforms when they were in position and ready for work.

These platforms were floated into position on pontoons and then the spuds were dropped through the boxes, by means of a floating derrick. After the spuds had been thus placed, differential pulleys were fastened to the tops of the spuds and to the corners of the platforms, and by means of these pulleys the platforms were raised from their pontoons which, when thus cleared, floated from beneath.

In general, the platforms were located about 3 ft. above high water. It will thus be seen that when located over the low portions of the reef, they stood on 8 x 8-in. legs, over 40 ft. in length, and without bracing of any description. It was found that the platforms shifted up and down stream, according to the flow of the tide, about 3½ ft. from the true position when the legs were vertical. The drills used by Lowe were of the largest size of the Ingersoll & Rand make, and were the same in size as those afterwards used by the Department. No uniform size of drill bar was used, as all the material was old stock, their size varying from 2 to 3 ins. in diameter. All the drills were turned down so that they fitted into 1½ ins. diameter standard chucks.

In almost every case the required length of drill was made up of three or four separate pieces connected together by double-ended chucks. In order to drill a hole deeper than the feed of the drill, namely, 3½ ft., it was necessary to lengthen the drill bar. This was sometimes done by means of the diver, but more often by replacing the whole extent of the drill bar by means of the derrick. This was a cumbersome and dangerous operation, especially in windy weather, when there was considerable swell on the exposed side of the pier. Operations were only just commenced when the first platform was wrecked, the swell from a passing steamer having overturned it.

The outfit at the commencement of operations consisted of one diver, one foreman, two blacksmiths and five deck hands, besides E. R. Lowe himself. While the drills were in operation, with the force enumerated, the drilling of the holes averaged about 13¼ lin. ft. per day with one drill at work.

All the drilling was done without any particular system, and no plans were kept of the location or the depth of the holes drilled, except by the Department (see Fig. 3).

The party doing this work made an effort at first to connect the holes drilled and charged by means of the diver on the bottom. The effort was not successful, however, and three days were wasted, without any result except the losing of the holes. Afterwards all connections between the wires leading to the holes were made on the surface of the water. When blasts were fired, powder and tools which were kept on the floating derricks were moved about 100 ft. away from the area blasted. Large amounts of powder were used in the first opera-

tions on this reef, as the pier not having been widened at the time the work of blasting was going on, it was possible to use much more powder than was found safe in later operations which came close to the widened pier. In one case 300 lbs. of Hecla powder, which is said to contain 40% of nitro-glycerine, were fired at one blast. A perceptible shock was felt on the pier 200 ft. away, and the water was thrown about 40 ft. in the air. As large blasts as this were not allowed again.

After the platform had been wrecked for the second time, two platforms were set up and lashed together, and an effort was made to run four drills on these two platforms at the same time. After a trial,

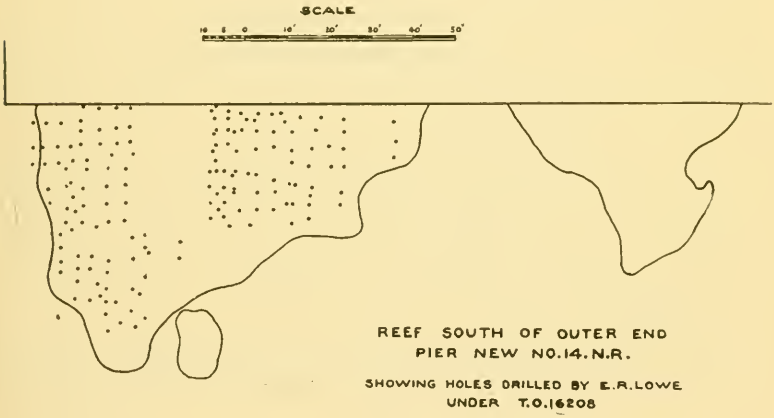


FIG. 3.

however, during which the vibration of the drills very nearly wrecked the platforms again, the work with four drills was discontinued, and afterwards only two, and for a very short time three, drills were operated at the same time. The two platforms lashed together collapsed suddenly, on a Sunday, when no work was being done, making the third collapse. The cause of this accident could not be determined. Two of the spuds were broken in this accident, and over six days were required to clear up the wreck. While the platforms were being repaired, some of the blasted rock was removed by means of divers, about 85 cu. yds., measured on the scow, being removed, with a daily average of $3\frac{4}{10}$ cu. yds., the force employed averaging ten men and two divers.

This work being considered too slow, the small dredge *Hussar* was placed at work dredging the blasted rock. This dredge had been built expressly for the recovery of the supposed sunken treasure that went down in the British ship *Hussar*, in Long Island Sound, during the period of the Revolution. The dredge was built to operate in very deep water, and was said to have dredged successfully in water 200 ft. deep.

The bucket of the dredge had a capacity of about 2 cu. yds., and was opened and closed by hydraulic power, a small rubber hose carrying the water from a pump on the scow to a hydraulic cylinder which formed part of the bucket. After a trial this dredge was found to be not adapted to the dredging of the blasted rock. The bucket being light and also being without poles, and more or less top-heavy on account of the heavy cylinder situated near the top and hinge of the bucket, caused it to fall over after it struck the uneven blasted rock on the bottom.

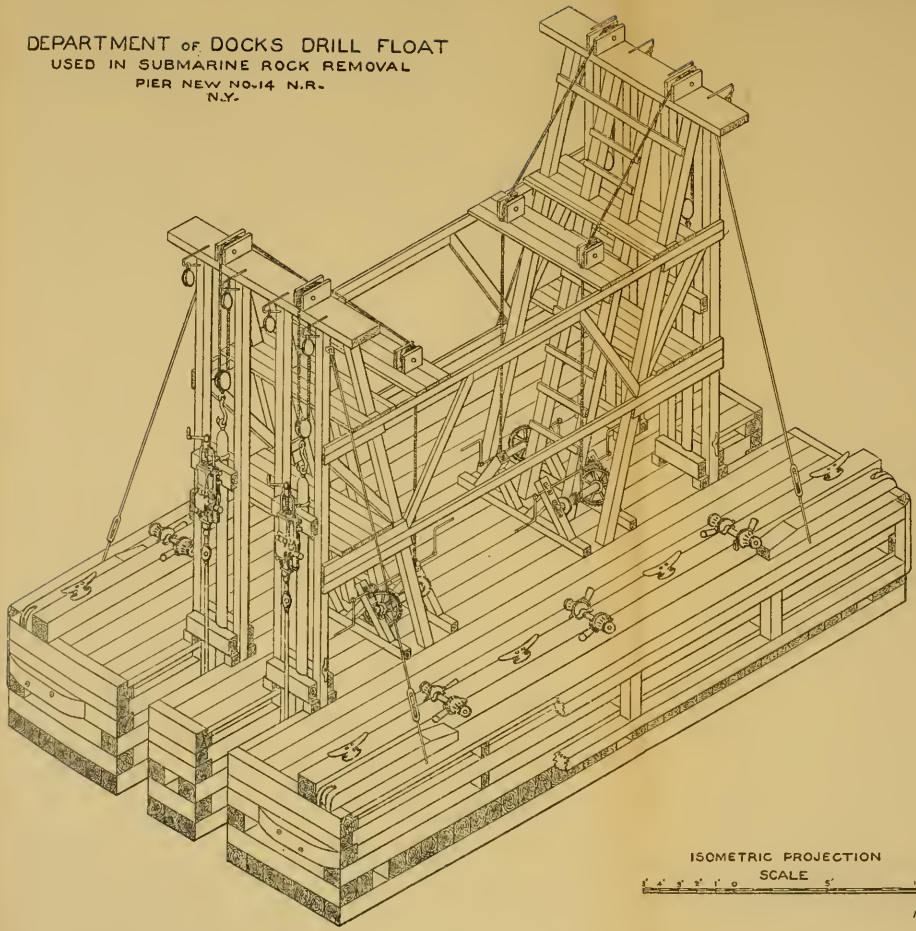
This dredge worked continuously from November 7th to 15th, and in that period excavated and removed about 116 cu. yds., scow measurement, or an average of about 18 cu. yds. per day. After this dredging was finished drilling and blasting were recommenced and continued to December 28th, 1892, when the work was abandoned by the contractor.

In all, during the period from July 25th to December 28th, 164 holes were drilled (Fig. 3) aggregating about 1 050 lin. ft. of 3-in. diameter hole.

Rock removed by divers	85	cu. yds.
" dredge	116	"
Total removed by contractor E. R. Lowe	201	"

All the powder used in the above work was of the grade known as 40% Hecla. All holes were charged with this powder in 2½-in. diameter tin tubes. Efforts were made to drill all the holes 3½ ft. below the 35-ft. grade required. This, however, the writer does not think was done, except in a few cases. Judging from the result of subsequent blasts made by the Department, it is his opinion that a large amount of the powder used was simply placed on the top of the rock. No means were taken to keep an accurate location plan of the holes. In fact, all

DEPARTMENT OF DOCKS DRILL FLOAT
USED IN SUBMARINE ROCK REMOVAL
PIER NEW No. 14 N.R.
N.Y.



ISOMETRIC PROJECTION
SCALE
5' 4' 3' 2' 1' 0 5' 10'

ABB 1/3/10

of this work depended on the intelligence and honesty of the divers, and the men employed in this capacity were very inefficient.

At the time just before this work was abandoned, Mr. Lowe informed the writer that he had actually spent more than $8 000, which was more than the total lump sum bid for the work. The discouragements consequent upon the failure of the plant that was used, and the coming of the ice season, when it would have become absolutely impossible to use the platforms, led to his abandonment of the work.

Dock Department Plant.—When it became evident that the work of the removal of the reefs around Pier No. 14 (new) could not be finished by the contractor who had taken the work on one reef, the Department took the matter in hand, and constructed the drill float (Plate XXXVI) for further operations, it having been decided to remove the reef on the north side of and near the outer end of the pier, and the one lying south of and close to the inner end of the pier, by Dock Department labor. A single-drill float had previously been used in the removal of rock to a grade of 14 ft. below mean low water on the East River. The governing idea in the construction of the large four-drill float was to use as much as possible the class of material which, when it should be taken apart, could be used again in the bulkhead wall construction. With this end in view 12 x 12-in. spruce timber was used in the construction of the float itself. This timber was found to be exceedingly buoyant, and from actual trial the buoyancy of 1 cu. ft. was found to be about 33 lbs. After the operations of removing the rock were completed and this drill float was taken apart, the timber was not found to be at all water-logged, although it had been continually immersed in water for more than one year. The dimensions of the drill float were about 22 x 33½ ft., deck measurement, and 6 ft. in depth. The construction of this float will be readily seen in Plate XXXVI the whole apparatus being practically floated on the two bottom courses of timber. Four drills were located on the float, operating through well holes, each of the drills being capable of drilling a hole 12 ft. in depth without changing the drill or the drill bar. The drills were raised and lowered in ways by two men operating a hand winch. Two Ingersoll and two Rand drills were used, the drills being fastened to a 6-in. cast-iron column, by means of the standard mining attachments, with only a few additions to enable the drill to be kept in a vertical position without turning. In drilling a hole the drills

were fed by the hand-feed until the feed was run out, when the winches were called into requisition, the drills lowered, the hand-feed raised, then operations continued as before.

It was thus possible with this machine to drill the holes to the required depth, without change in the drill or drill bar, unless for other reasons than the deepening of the holes. In order to hold this drill float steady against wave action, and also against tidal rise and fall, four anchors were used, which consisted of ordinary pile-driver hammers, weighing about 3 000 lbs. each. The drill float was accompanied by the standard Dock Department 12-ton derrick, containing two 40 H.P. boilers, and having a single mast with two booms. In locating the drill float, the derrick lifted the four pile-driver hammers, the hammers being rigged in couplets, two for each end of the float. After the hammers were clear of the bottom, the derrick and float alongside were floated into the desired position over the reef, and the hammers were let go and cast free from the booms of the derrick. Other lines from these hammers, or anchors, which ran over the pulleys at the corners of the drill float, were then made fast to the hand winches, and the whole drill float hove down by means of these winches, until the deck of the float stood about 1 ft. or 18 ins. above the surface of the water. Connections now being made from the boilers on the derrick to the steam rock drills, the operation of drilling could commence from what had become a fairly stable structure.

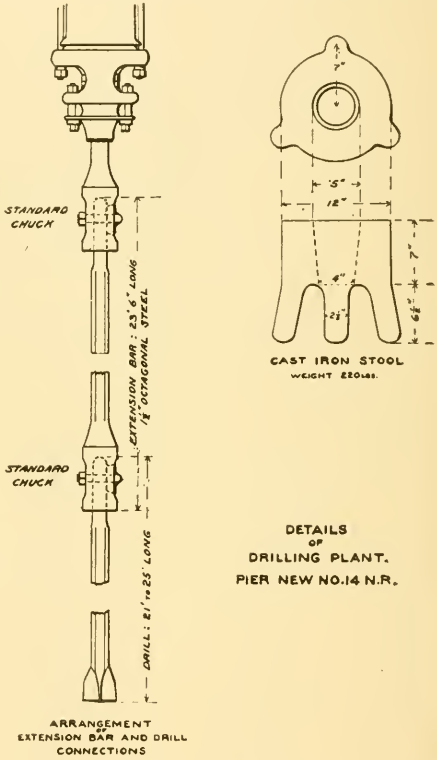
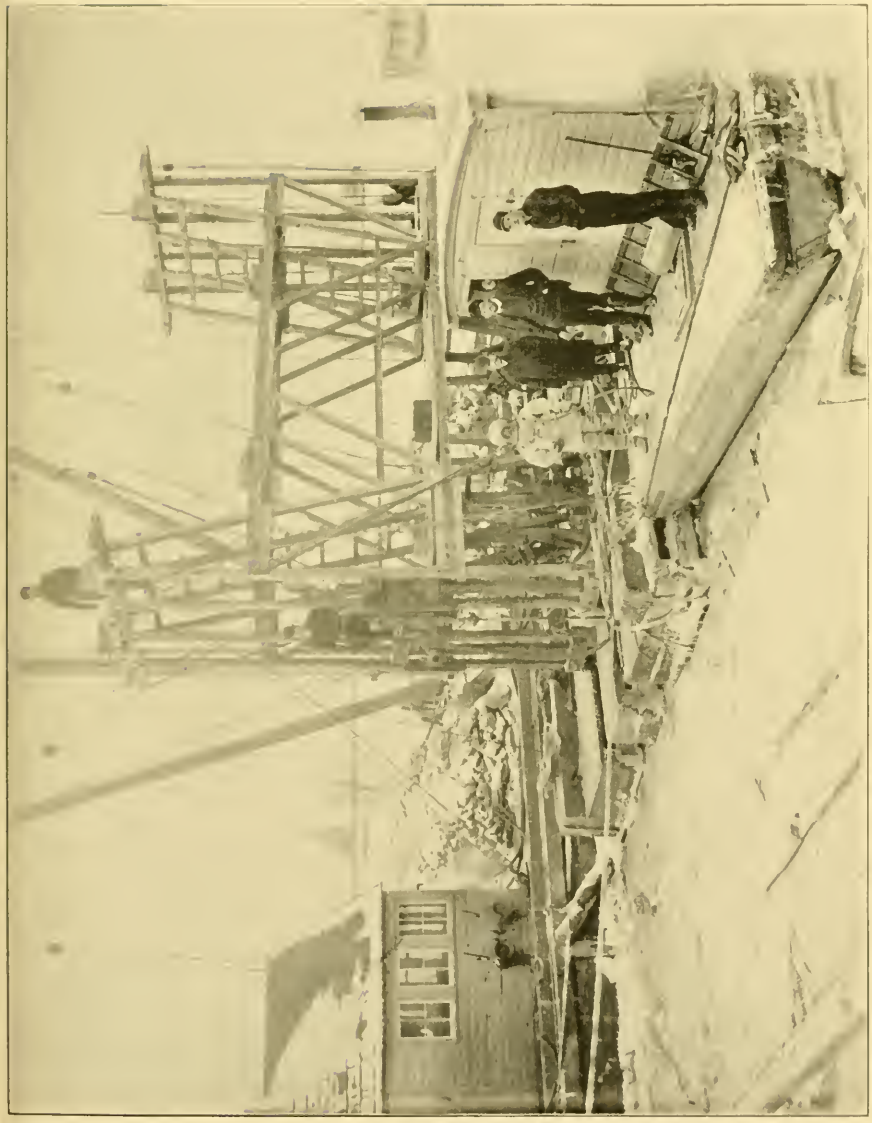


Fig. 4.

PLATE XXXVII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 729.
BENSEL ON SUBMARINE ROCK EXCAVATION.



Where these operations were conducted, and during the period of time which they covered, there was considerable high wind and a large amount of ice, the waves oftentimes rising to a height of over 3 ft. along the side of the pier, and washing over the deck of the float. At one period, about the latter end of December, this drill float operated while surrounded entirely by ice over 6 ins. in thickness. Plate XXXVII shows the drill float at this time.

A single-drill float was used entirely on the reefs south of the inner end of the pier, and on the one south of the outer end of the pier, when the Department finished up and completed the work which had been abandoned by the contractor.

The drill bars used by the Department (Fig. 4) consisted of two pieces of octagon steel 1½ ins. in diameter, and when joined together made a total length of 45 to 50 ft. The two pieces were ordinarily of about equal length, one piece, the extension bar, having welded at one

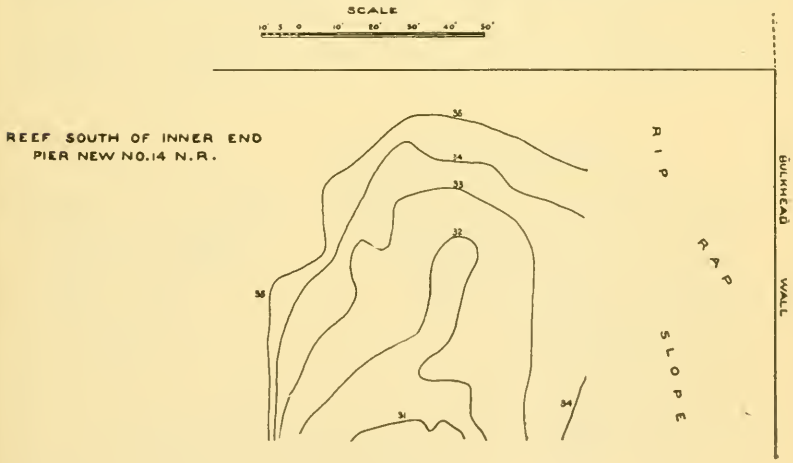


Fig. 5.

end the ordinary standard drill chucks, and the other end being turned so as to fit into the chuck of the drill; the lower length of the drill bar formed the drill proper, one end being fitted into the chuck on the extension bar, and the other end being upset and formed into a drill point with a diameter of 3 ins.

In drilling an 8-ft. hole the diameter of the drill decreased to 2½ ins., and sometimes, in especially hard rock, to 2¼ ins., diameter. Toward the close of the work, when the holes in the chucks had be-

come considerably worn, difficulty was found in making the connections tight, both at the drill and at the end of the extension bar, and had the work gone further, a more positive chuck, not depending on the friction of a key, would have been made. The drills were operated with a steam pressure of 95 lbs. per square inch at the drill.

The locations of the reefs made the conduct and procedure of the work different on each of the various areas. On the reef south of the inner end of the pier (Fig. 5) mud formed so quickly that it was found impossible to clear off with the pump and to have the reef remain clear of mud long enough to permit the drilling of any number of holes before blasting them. The reef north of the outer end of the pier, however, was kept entirely free from mud by the current, and we were enabled to drill about half the area of the reef with holes before commencing the operation of blasting. On the reef south of the outer end of the pier, after the work had been abandoned by the contractor, the Department put a dredge to work and cleared the area of all the loose rock. The reef was then found to be in the condition shown in Fig. 6. The top surface of the rock being soft and seamy,

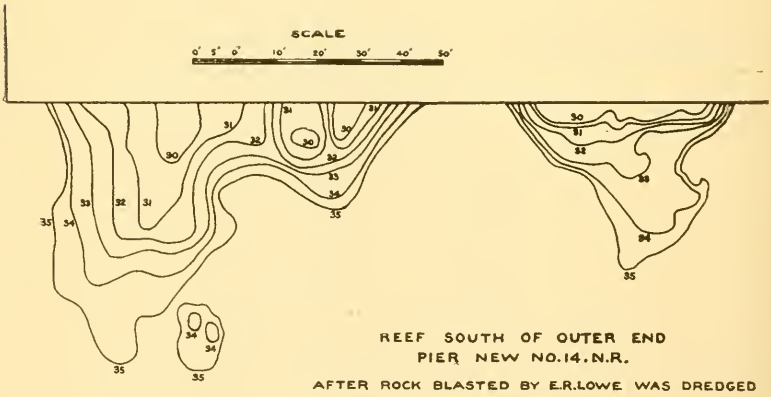


Fig. 6.

considerable difficulty was found in drilling holes in this reef, and a large portion of the rock was removed or reduced to powder by surface blasting. The small portion of this reef lying inshore of the main body of the reef on the south side of the pier was removed entirely by surface blasting, only a small depth of rock having to be removed.

Pier No. 14 was widened by the addition of a 50-ft. strip to the southerly side, making it, as it now exists, 125 ft. in width instead of 75 ft., as formerly. This work of widening had been carried on during the time the contractor had been operating on the reef south of the outer end of the pier, and at the time that the Department commenced operations this work had been nearly completed and a crib 30 × 50 ft. sunk at the extreme outer end of the pier, where it was impossible to drive piles. The effects of the surface blasts on this crib were quite remarkable. At one time a blast of about 15

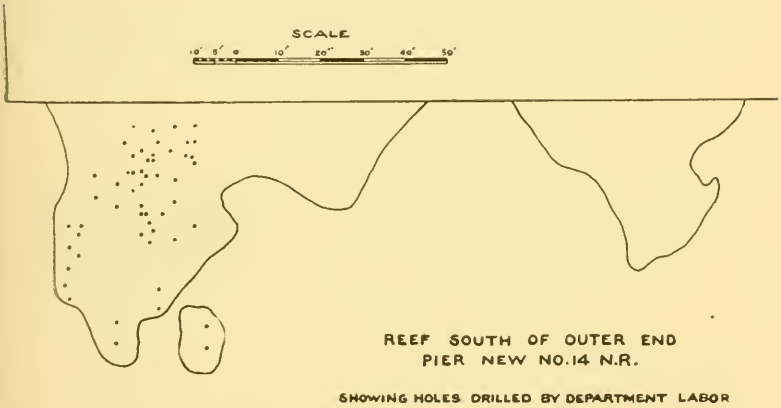


FIG. 7.

lbs. of gelatine, located about 15 ft. south of the crib when fired, threw it in the air about 1 ft. And as the crib was located on a rock bottom which shelved out shore, each firing of a surface blast threw it further out in the stream. Holes were drilled in the rock close to the outer edge of the crib on the bottom, and four drill bars placed in the holes, bearing against its outer timber. After it had brought up solidly against these bars, no further movement was made by the blasts.

The Department drilled 53 holes in this reef (Fig. 7) after taking hold of the work, and, in addition, by the use of a considerable amount of powder in the way of surface blasts, the reef was removed by the dredge to the condition shown in Fig. 8, and then the remainder of the rock taken out by divers and the use of surface blasts.

The Department commenced the operations on this reef on March 18th, and finished the work on October 26th, 1893.

On examination made by divers, the entire area of the reef south of the inner end of the pier was found to be covered with from 5 to 7 ft. of mud, soft on top, but quite firm and solid for the bottom 3 ft., although this reef had been dredged to the solid rock only about a week previous.

Operations were commenced on this reef by trying to clear it of mud, a 10-in. rotary pump on the derrick being used. As an experiment, a trench was dug about 20 ft. in width, running from east to west across the entire extent of the reef, or up to about the bottom of the rip-rap slope which forms part of the bulkhead wall construction. The pumping of this trench required six consecutive days, after which the

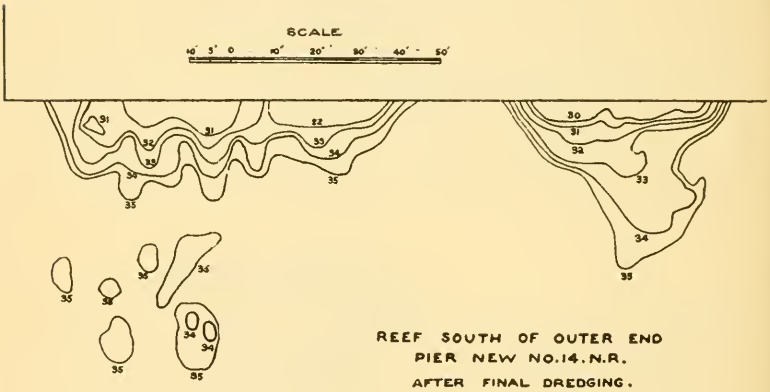


FIG. 8.

drilling was commenced with the single drill float. After drilling for about one month, during which time 76 holes had been drilled, and about half of them blasted, it was found that the mud was forming so rapidly that there was danger of losing those holes that had not been blasted, in spite of the fact that all of them had ½-in. iron rods in them which projected about 2 ft. above the surface of the rock.

No more pumping was done on this reef before the drilling, but the holes were afterwards drilled through the mud, and the only pumping that was necessary was done where the mud had become so deep as to prevent the diver loading the holes that had been previously drilled.

The attempt was made on this reef to charge and fire the holes soon after they had been drilled, and not to have any large number of them drilled in advance of the blasting. This was done in order to save the

holes and to save time in finding them through the deep mud. But it resulted in the loss of quite a number of them by their being destroyed by contiguous blasts.

Rack-a-rock powder was first used on this reef, the charges being placed directly in the holes without the intervention of tin tubes, the holes where this powder was used being situated in that portion of the reef that was first pumped clean.

Difficulty arose in the use of this powder, however, the divers claiming that it did not throw out the rock, and quite a number of charges burning without exploding. Where this occurred, the cartridges containing the exploders either partly or entirely burned and the remaining cartridges or sausages had to be removed by the diver.

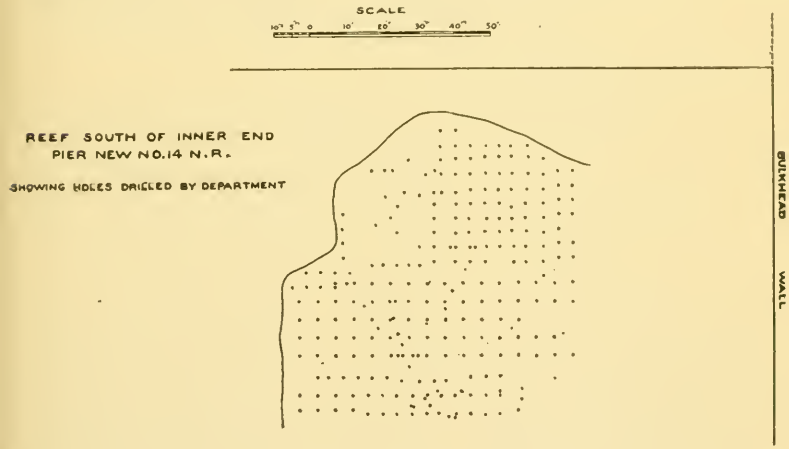


FIG. 9.

After 420 lbs. of this powder had been used, the use of nitro-glycerine powder was commenced. That known as forcite powder, containing, it is stated by the maker, 60% nitro-glycerine and 40% of a patented mixture of wood pulp, gun cotton and nitrate of soda, was the first used. The burning of the powder in the hole occurred afterwards with the forcite powder, but it was traced to the use of poor exploders that had been bought in haste and had probably been kept in stock some time.

After using a small quantity of this 60% forcite powder, what is known as forcite gelatine was used, and nearly the entire remaining work done by the Department was with this powder. Gelatine is

claimed to contain 95% of nitro-glycerine and 5% of gun cotton and some other absorbent. It was claimed to be extra safe on account of the difficulty of exploding it, the makers claiming that this difficulty was so great that the exploders should always be placed in a cartridge of the lower grades, say, 40 or 60% powder. There was no difficulty, however, when a double-strength exploder was placed in the gelatine itself. In the use of this powder, however, it was found that a weak exploder would simply set it burning, with slow combustion, a dark, reddish gas being evolved, which smelled not unlike chlorine. In some of the holes the entire charge burned out in this way, while in others the cartridge containing the exploder, and sometimes only a portion of this cartridge, would burn. All of these charges that burned slowly in this way occurred in the reef south of the inshore end of the pier, and with a particular lot of exploders that were afterwards found to be poor.

One of the difficulties in the use of this nitro-glycerine powder is the fact of its freezing and becoming unreliable at a temperature lower than 42° Fahr. This necessitated keeping a fire in the powder house.

In this case a small range was placed in the powder house, which was a 10 x 10-ft. structure placed on a scow and covered on the outside with tar-roofing paper, and the temperature inside kept constantly between 65 and 75°. During the cold weather the powder always arrived in a frozen condition, and the thawing out was done by immersing a galvanized iron bucket filled with the gelatine cartridges in a tub containing water that had been heated on the range to a temperature of not above 100° Fahr. There seems to be considerable doubt as to what is the dangerous temperature of this powder, some people who had used the gelatine claiming that it would stand 200°. No difficulty, however, arose in its use, limiting the temperature as stated, and the powder never became so soft as to run and become unmanageable. Using the bucket and the water in this way none of the cartridges ever came in contact with either the hot water or any hot metallic surface. Owing to the large amount of handling which has to be gone through with in using the powder which has become frozen, the cartridges, which were 2½ and 2¼ ins. in diameter and 8 ins. long, were wrapped carefully in extra heavy paraffine paper before being sent from the factory, and this paper was never opened, except in the case of the one cartridge into which the exploder for each charge was inserted.

The drilling was commenced on this reef, south of the inshore end of the pier, on September 2d, 1892, and continued without interruption, except for blasting, until March 13th, 1893, during which time 231 holes were drilled (Fig. 9), aggregating about 162 lin. ft. all the holes being 2½ and 3 ins. in diameter, and having been drilled 3 ft. below the 35-ft. grade. The first dredging was done from March 13th to 22d, inclusive, 703 cu. yds. of mud and rock being taken out, the dredge being used with a scoop. After the dredge had taken out all that

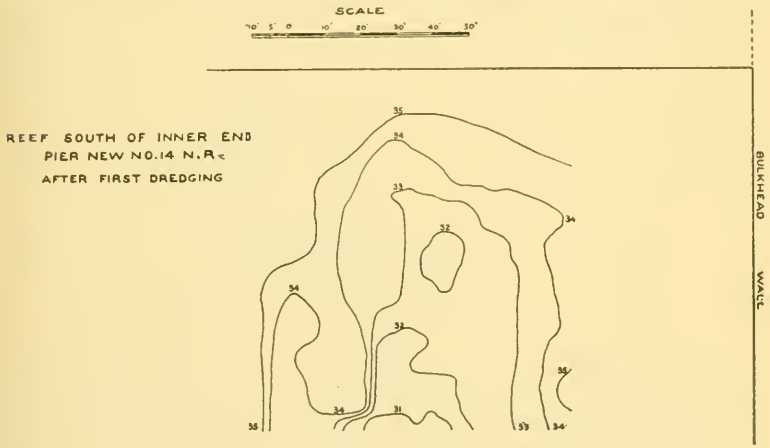


FIG. 10.

seemed possible (Fig. 10), an examination by divers showed that there was still much loose rock on the bottom, and also some pieces that had been detached from the bed-rock, which lay too close together for the dredge to remove. After the dredge was through this first dredging, 15 holes were drilled and fired, and a number of surface and seam blasts were set off; after which, the dredge was turned in again. Altogether, the dredge was at work eight separate times on this reef; and between each time drilling and blasting holes, also, seam and surface blasts were set off, to loosen the rock.

The condition after final dredging is shown in Fig. 11.

In all, there were 79 holes drilled and blasted between the time that the dredge first commenced work, and the time when the removal of the reef was finished. During the same time 86 cu. yds. of loose rock that had escaped the dredge were taken up by divers. The work on this reef was finished on November 2d, 1893.

Operations were commenced on the reef north of the outer end of the pier (Fig. 12) on October 19th, 1892, when an examination by divers disclosed the fact that, although the reef was pretty fairly clear of mud, it was encumbered by a quantity of rip-rap. About 30 yds. of

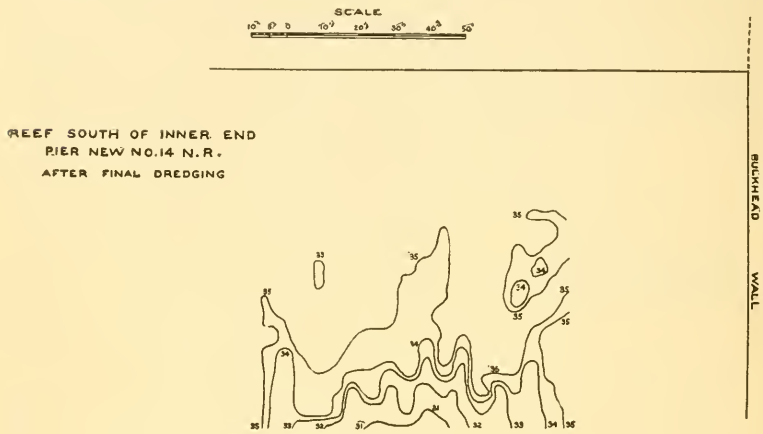


FIG. 11.

this were removed by the divers before the drilling commenced. The reef was covered on the top, in addition to the rip-rap, with some sand and hard-pan, and it was deemed advisable to pump this off. This operation proceeded so slowly, however, that it was abandoned, and actual drilling was commenced on November 11th, 1892.

As stated before, an endeavor was made in this reef to drill the holes over one-half the whole area before the blasting operations were commenced; exception, however, was made when the necessity for repairs compelled the abandonment of drilling, and also where holes were placed close to the side of the pier, and there was danger of losing them on account of the tumbling down of the rip-rap under the pier. At these times blasting was done, as became necessary.

The rip-rap under the pier, which became very troublesome later, was placed to a grade of 15 ft. below mean low water, under the pier, sloping down to a grade of 20 ft. at the side of the pier. Every blast dislodged some of this rip-rap, and it is estimated that on the reef north of the outer end of the pier there was removed, besides the solid rock, about 400 yds. of it, a considerable portion of which, existing, as it did, close to the side of the pier, was about as expensive

to remove, either by the diver or the dredge, as was the blasted rock itself.

The idea in drilling the large number of holes in this reef before doing any blasting was to try to escape the delay and expense found to occur on the reef south of the inshore end of the pier, where new holes had to be drilled close to where the holes had previously been blasted, and the rock had been left shattered and in seams, and yet not loose enough to be removed by the dredge. Often when a drill struck any of these seams, the hole had to be abandoned and a new one sunk near it.

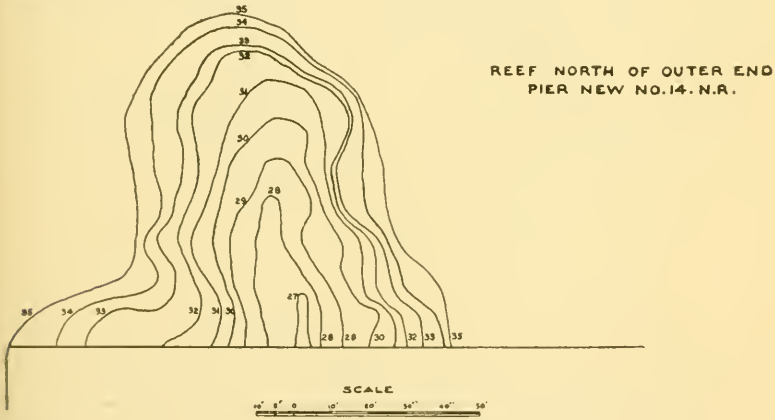


FIG. 12.

In order to keep track of the holes for the subsequent blasting, and to enable the men on the surface to know the location of those that were being charged, wooden plugs were made with the number of the hole cut into them, and with a hole through the axis, in which was inserted an iron rod ½ in. in diameter. As soon as the holes were drilled, these plugs, with the iron rods through them, were inserted in the holes in the rock and tamped firmly in place by the divers. In the charging of the holes afterwards a diver was dropped down about over the spot where the holes to be charged were supposed to be located, and he removed the plugs of the nearest holes and sent them to the surface. It could then be readily seen whether he was located on the bottom correctly, and also whether he was charging or cleaning out the holes intended.

After drilling and blasting the holes on the westerly half of the

reef the drilling was done on the easterly half, the holes being commenced at the easterly edge and worked westerly, and located about as shown in Fig. 13. It was found that the force of the tide had considerable influence on the location of the hole on the bottom, and examples were found with a variation of 3 ft. between the location of the drill on the surface and that on the bed-rock below. For almost the entire first series of holes, drilled before any dredging was done, no stool or guide for the drill on the bottom was needed or used, and the long-drill steel vibrated in a circle of probably 4 ft. in diameter on the bottom under the influence of the strong tidal current before it drilled sufficiently into the rock to guide itself. This, of

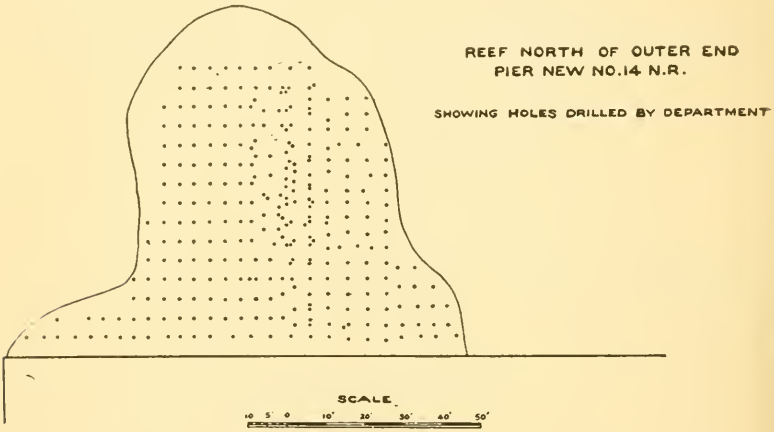


Fig. 13.

course, did not occur where the rock was either soft on top or overlaid with sand or hard-pan. The cast-iron drill stool (Fig. 4), weighing 200 lbs., was used in cases where the holes had to be accurately located, or where the hole was located in a sloping position in the rock.

All the holes in this reef, as well as those drilled in the other reefs by the Department, were drilled to a grade of 38 ft. below mean low water, except close to the sides of the pier, where the bottom was sloped up, as shown in Plate XXXV. In some cases, where redrilling was done over areas of the bed-rock where it had formerly been drilled, the rock was so disturbed by the previous blasting that it was impossible to get powder down to the bottom of the hole. In almost every case, however, the explosive was placed down as far as 35 ft. below

mean low water. After all the regularly spaced holes located (Fig. 13) were drilled and fired, the dredge was put to work on March 22d, working from that date until the 28th, and excavating and removing in that period 229 cu. yds., scow measurement.

Soundings were then taken, and the reef found to be in the condition shown by Fig. 14, which plainly shows a ridge through the center of the reef nearly as high as the original grade.

An examination by divers disclosed the fact that, although the rock was broken and seamed where the grade was high, the broken stone lay in such a position that the dredge skimmed over the top and did not penetrate into the mass. Charges were prepared, and wherever a seam could be found, a charge was placed and fired. After this was

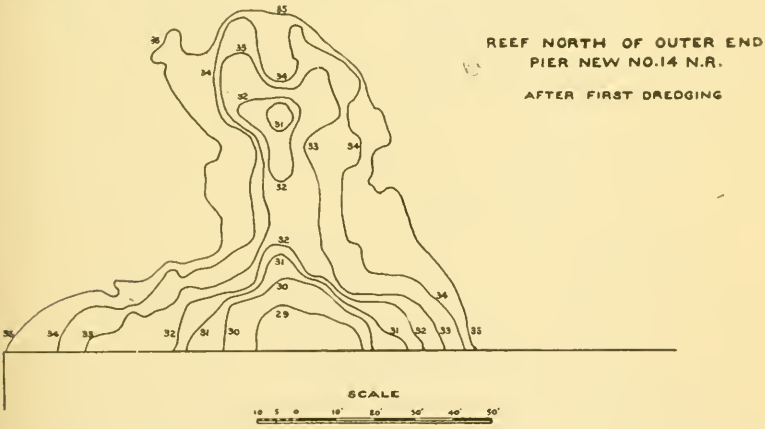


FIG. 14.

done, the dredge was set to work again from April 5th to April 14th, and in that period excavated and removed 471 cu. yds., scow measurement. Soundings taken showed still several high portions of the reef. Drilling was recommenced between April 15th and May 2d, 31 holes being drilled and blasted in this period. The dredge was then turned in again, working from May 3d to 9th, and in that period removed 120 cu. yds. Soundings still showed several high places. Thirty-three holes were drilled and blasted before the dredge was put to work again. This trip of the dredge succeeded in removing only about 100 cu. yds. in four days. The divers reported much loose rock, part of which could be felt from the surface. A trial was made to see what could be done with divers, and in one day 6 cu. yds. were re-

moved. The reef was now in fair shape, except close to the pier, where it was impossible to use the dredge. After drilling 29 holes, blasting a number of seams and firing a few surface blasts, the dredge was put to work again on June 6th, and between that date and June 12th, 152 cu. yds. were removed. Thirty-six holes were then drilled, after which the dredge took out 113 cu. yds. in three days. After drilling 33 holes and blasting them, where the rock was a very small amount above grade, the dredge was put to its final work on this reef on July 24th, and from the 24th to the 28th removed 100 cu. yds. Soundings taken after this showed the reef in the condition shown in Fig. 15.

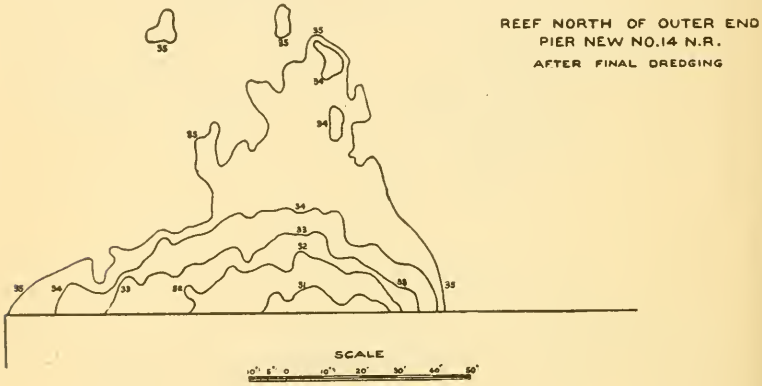


FIG. 15.

As there was then such a small amount of rock to be removed, and the trimming of the bottom close to the pier would have to be done by the divers in any event, the work of removing the remaining portions of the rock by means of divers was commenced and carried along until September 30th, when the reef was cleared to a grade of 35 ft. below mean low water, except close to the sides of the pier, where the rock was trimmed to fit the bilge of the American line ships *Paris* and *New York*, as shown in Plate XXXV.

The nature of the rock in all these reefs was about the same, consisting of gneiss and mica schist seamed with quite extensive veins of quartz. This made both the drilling and the blasting difficult, as the soft mica rock in some places was extremely difficult to remove by surface blasting, even when only a small height was to be knocked down.

The holes drilled by the Department in all the reefs for the first series were spaced 6 ft. apart in northerly and southerly direction, and 5 ft. apart easterly and westerly. The holes being drilled in a vertical direction, the result of the blasting seemed to be to stack the broken stones against each other, and not to loosen and throw up the mass. Divers described this bottom as being often times like a pile of gravestones, one stone lying against another.

Dredging.—The dredging of the blasted rock was very disappointing. All kinds of buckets were used, including the scoop, clamshell buckets in two different sizes, 4 and 7 yds. capacity, and the grapple. There was little or no perceptible difference in their effects. On the first day the dredging was done on the reef south of the outer end of the pier; fairly satisfactory work and progress were made, 100 cu. yds. being excavated and put into the scow. The writer thinks it probable that this progress was possible because E. R. Lowe had made a large number of surface blasts, the charges being supposed to be placed in holes, and the rock was powdered pretty well all over the top of the reef, and no difficulty was experienced in its removal. The number of hours that the dredge was employed on each separate reef is as follow:

Reef north of outer end	389 hrs. 25 min.
Reef south of outer end	266 " 50 "
Reef south of inner end	230 " 05 "

In one case, directly after the dredge had been stopped because it was doing work of little or no consequence, 30 cu. yds. of stone were sent up by the divers, who simply loosened the stone on the bottom with their bars, the broken stone having formerly lain in such a position that the dredge buckets skimmed over the top. It would seem as if part of the explanation of the slow work done by the dredge lies in the fact that the rock would be best operated on by a machine using the scoop, and in the fact that there is no machine, so far as the writer is aware, certainly none in this vicinity, capable of operating a scoop in a 40-ft. depth of water. Extensive alterations would have to be made in the rig of the machine, in order to get a greater horizontal thrust to the scoop. The dredge employed on this work was one of the largest in this harbor, but to rig it to use the scoop, or dipper, for the depth required, simply meant the extension of the dipper handle, with no increase in the overhang of the boom, which would cause an

increase in the vertical component of the force exerted by the chains, and a consequent decrease in the thrust or horizontal component of the force.

This dredge, like others in the harbor, is built to operate and to dredge to a depth of 25 ft. below mean low water, but, though dredging may be done with it to a depth of 30 ft. in mud or sand, the increase to 35 and 40 ft., and the operations being confined to rock, were conditions too hard for it to master satisfactorily.

The work here described was done under the personal direction of the writer as Assistant Engineer of the Department of Docks, of which G. S. Greene, Jr., M. Am. Soc. C. E., has been for a long period Engineer in Chief.

The cost of the work divided into the several reefs is as follows:

Reef North of Outer End—	
Labor	$16 949 59
Material	3 395 42
Dredging	9 731 25
Towage	548 73
Reef South of Outer End—	
Labor	6 974 30
Material	1 816 84
Dredging	6 662 50
Towage	274 36
E. R. Lowe paid on account	3 798 67
Reef South of Inner End—	
Labor	13,217 16
Material	2 526 24
Dredging	5 752 08
Towage	548 73
Total	$72 195 87

The cost of building the two drilling floats is as follows :

Labor	$946 18
Material	4 101 50

The calculated amount of rock removed is as follows :

Reef north of outer end	766 cu. yds.
Reef south of outer end	357 "
Reef south of inner end	407 "
Making a total of	1 530 cu. yds.

of solid rock measured in place.

Besides this amount of solid rock, there was removed about 450 cu. yds. of rip-rap, thus making the total 1 980 cu. yds. of rock removed.

The amount of rock removed, measured in the scow, is as follows:

Reef north of outer end, by dredge	1 285	cu. yds.
" " " by divers	150	"
Reef south of outer end, by dredge	843	"
" " " by divers	118	"
Reef south of inner end, by dredge	2 677	"
" " " by divers	150	"
Making a total of rock removed and measured in the scow	5 223	cu. yds.

DISCUSSION.

J. F. O'Rourke, M. Am. Soc. C. E.—What kind of rock was that ?

John A. Bensel, M. Am. Soc. C. E.—Gneiss, with veins of mica schist, and quartz.

T. Guilford Smith, M. Am. Soc. C. E.—I would like to ask about the $72 000 the Department spent in addition to the $8 000; the original estimate of the Department was about this, was it ?

Mr. Bensel.—There was no estimate made; the $8 000 paid Lowe is included in the amount of about $72 000; as may be seen on page 252, bids were received, of which Lowe's was the lowest. The bids were lump sum prices, to make 35 ft. at low water on the reef south of the outer end of the pier.

Desmond FitzGerald, M. Am. Soc. C. E.—What has been the ordinary price in 25 ft. of water ?

Mr. Bensel.—It varies greatly, probably between the limits of $35 and $11.

Mr. O'Rourke.—Did you distribute the expenses so you could tell how much the drilling cost ?

Mr. Bensel.—I have not done so in this paper. The dredging is in the neighborhood of $20 000, the construction of plant was about $5 000, and the amount paid Lowe about $8 000. The remainder, after subtracting the above, is the cost of the drilling, blasting, sounding, tubing and pumping the rock.

Mr. Smith.—You have the plant left ?

Mr. Bensel.—Yes, but probably no use for it in the near future.

Mr. O'Rourke.—Was there ever considered the possibility of drilling through the mud ?

Mr. Bensel.—As stated in the paper, most of the drilling where the mud occurred, on the reef south of the in-shore end of the pier, was done through the mud. In loading the holes, however, where the mud was more than 3 ft. in depth, it became necessary to pump, in order that the diver might operate.

Mr. O'Rourke.—I mean without a diver.

Mr. Bensel.—A trial was made in drilling through a wrought-iron pipe, but the length of the pipe, over 50 ft., and the consequent difficulties in its handling made the work slower and more expensive, and its use was therefore abandoned.

R. A. Cummings, Assoc. M. Am. Soc. C. E.—Has the Lobnitz system been considered in doing this work ?

Mr. Bensel.—No bids were received from any one using that system.

Mr. Cummings.—I am informed there is a machine to operate on this principle being built in New York for rock excavation ?

Mr. Bensel.—There is one in Troy, working on a Government contract. I doubt if it would have worked in this case with the hard rock that was met with.

Mr. Cummings.—I would like to say for the information of the members that there is a dipper dredger in this country operating in a depth of 40 ft. of water. It was illustrated and described in the technical press some time last fall.

G. S. Greene, Jr., M. Am. Soc. C. E.—Is that on shale ?

Mr. Cummings.—It is on hard material.

Mr. Greene, Jr.—I think I know the work, but I do not think it has been worked yet at so great a depth as 40 ft.

Mr. Cummings (by letter).—The dredge I referred to was designed for 40 ft. depth of working, and was built for the Harbor Commission of Montreal.

The depth to which the Montreal Harbor Works are being constructed is 27½ ft. at low water. Inasmuch, however, as in the spring of the year, the water frequently rises 15 ft. above low water, the dredges all have a capacity of going to a depth of 40 ft. in order to reach the bottom during high water. There are some dredges that can work to 41½ ft.

Mr. Greene (by letter).—Mr. John Kennedy, M. Am. Soc. C. E., informs me that Mr. Cummings is correct, and that such dredges have been used for excavating shale at 40 ft.; and that he designed a dredge for excavating phosphate rock at 42 ft. depth for South Carolina.

I do not think that rock so hard as that referred to in Mr. Bensel's paper has before been excavated to a depth of 40 ft. below the surface of the water.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

730.

Vol. XXXII.—September, 1894.

ON FORM OF RAILWAY EXCAVATIONS AND EMBANKMENTS.

By D. J. WHITTEMORE, Past President Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

Nowhere in quiescent Nature do we find earth surfaces in right line planes, or changes in direction of same made by abrupt angles, yet it is the general practice in laying out and constructing railway excavations and embankments to establish slopes on such planes intersecting the natural surface of the ground and the formation level of the road-bed in a well-defined line.

These conditions are never, or rarely ever, maintained. Storm water breaks over the crest thus formed, seeking and making channels of least resistance down the unprotected slopes, bringing with it earth from the crest and from immediately below it, filling the ditches in excavations. Embankments suffer change of form from similar cause; and immediately after the line of railway is opened for traffic the ditching train is called into service to remove the slush from ditches and to widen embankments, at a cost of from $1 to $2 per cubic yard; and this expense is continued year after year, and charged to opera-

tion. Often this expense during the first year of operation will exceed the cost of forming and protecting the slopes of excavation on the plan shown by the diagram herewith, which, with the above remarks, the writer submits without further comment to the consideration and criticism of the members.

DISCUSSION.

Foster Crowell, M. Am. Soc. C. E.—In looking over this paper by Past President Whittemore, I have been impressed both by its brevity and its comprehensiveness. I have rarely seen so much contained in twenty lines. It hardly needs anything more.

But I can testify from my own experience that the views expressed in it, not only as to the adoption of modified slopes for railroad earthwork, but also concerning the general principle that the work of construction should be, so far as possible, complete, and not left in a condition to entail excessive expenditure in operation, cannot be too strongly impressed on engineers.

When my acquaintance with earthwork began, many years ago, the setting of slope-stakes was chiefly a mathematical exercise, entered into with great zeal and mistaken faith in the permanence of plane surfaces in new fills and cuts ; but I soon had an opportunity to learn the error of such ways, in laying out slopes in Fairmount Park (Philadelphia), so as to "stand," and to resemble Nature.

The experience which I gained there was afterwards carried into railroad building, and demonstrated the advantage of following Nature's forms as far as possible, and in the manner which Mr. Whittemore sets forth.

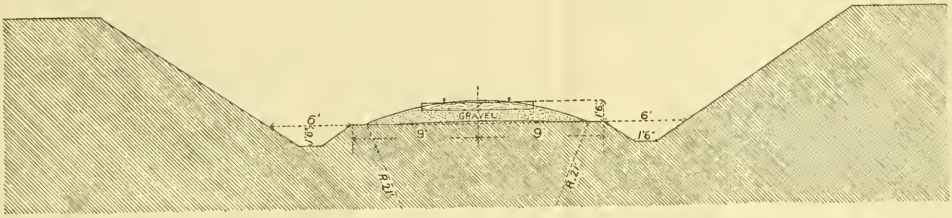
I also learned that it was a great deal better and cheaper in the long run to move material once for all and charge it to construction, than to handle a similar quantity several times a year thereafter and charge it to maintenance.

I might point out, further, that the desirability of flattening or rounding off the top of a cut is emphasized in cases where there are catchment ditches, which saturate the ground and increase the tendency to break away.

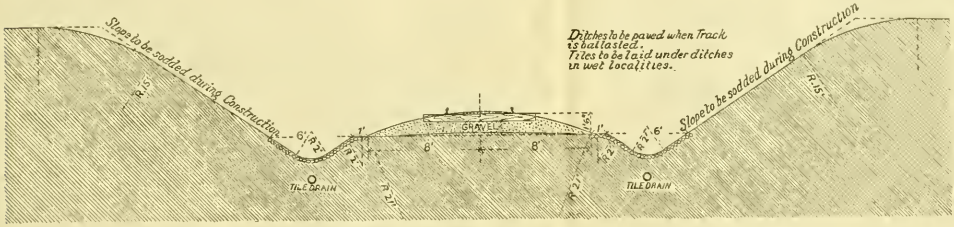
The toe of a rectilinear embankment, if left to itself, will come to a curve of stability; the shoulder will, at the same time, break down and slough away. Nature should be assisted at both points.

It not infrequently happens that excess material is wasted at the nearest available spot to save extra haul, while at other times, borrow

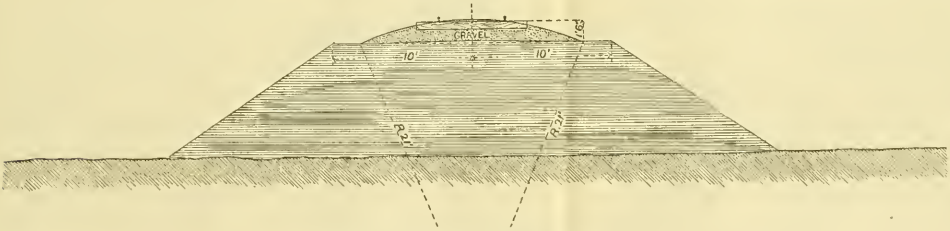
Customary Section of Roadbed in Excavation.



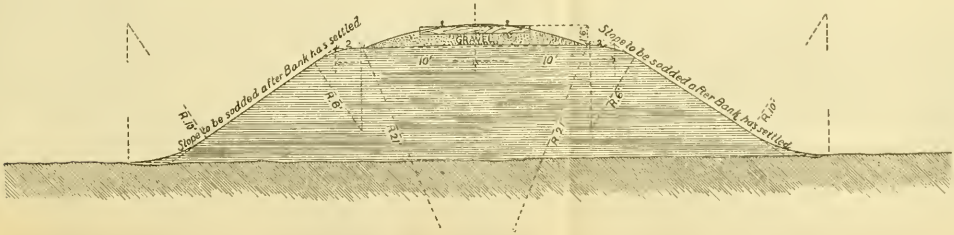
Proposed Section of Roadbed in Excavation.



Customary Section of Roadbed on Embankment.



Proposed Section of Roadbed on Embankment



is obtained from a distance; by keeping the above principle in mind and utilizing surplus excavation to that end, the banks can be put in an enduring shape with an ultimate saving in cost.

F. S. Washburn, M. Am. Soc. C. E.—The title of the paper, as I understand it, is "Form of Railway Excavations and Embankments;" and in examining the diagrams the eye is first impressed with the differences in form rather than with any novel mode of construction. But closer inspection develops to my mind that, so far as the forms of the proposed sections are concerned, they are very nearly what Nature will herself make the ordinary slopes in the course of a short time. I cannot see that a paper, based simply upon the rounding off of the angle on top, and rounding the angle at the ditches, would have great practical bearing. The paper says very little of what the diagram shows, upon close inspection, to be very important. It indicates that the slope is to be sodded during construction; that ditches are to be paved, and tile-drain laid. The futility of a young assistant engineer's pride in his new earth slopes has been dwelt upon, but let us imagine for an instant the state of mind of a chief engineer, whose assistants asked for sod, broken stone and tile-drains on new construction. In short, it seems to me, that the importance of the form of the embankment, as bearing upon the cost of maintenance, is very small, and that the cost of maintenance is reduced to a much greater extent by the use of sod and paving and tile-drains, and that this feature of the subject is not dwelt upon to a very great extent in the paper.

K. E. Hilgard, M. Am. Soc. C. E.—The preceding speaker reminds me forcibly of the first "set-down" I was served with when engaged upon railroad construction through prosperous farming and suburban property in one of the Northwestern States.

I had accidentally commenced my practical engineering on railroad and canal construction in beautiful Switzerland, and there I had been used to seeing the embankments sodded over, or seeded at least, in due season after their completion. Of course, I was impressed with the fact that this afforded an excellent and cheap method of protection, if judiciously applied in its proper place. I was still young when I advanced the opinion to my then chief over here that the same should be done in that case; but I shall not easily forget his prompt, expressive answer.

I am glad to know that so eminent an engineer and authority as Mr. Whittemore should personally in so few lines state that there is even economy in this method, thus strongly advocated by him, and I feel vindicated now, and that I may forgive my former chief, and subsequent friend, forever.

Mendes Cohen, Past President Am. Soc. C. E.—In listening to this paper I am impressed with the fact that we must be coming to the millennium in railroad practice.

I am surprised and gratified to find that our honored Past President, the distinguished chief engineer of a prominent line of railway, is able, as the result of his long experience, to recommend to the younger members of the profession so thoroughly effective a treatment of the slopes of excavations and embankments.

The trouble always was, in years gone by, that with extremely limited means engineers were expected to secure a graded roadbed at the least cost, and that meant necessarily with the least possible amount of excavation or embankment, as the case might be.

Most of us were well aware that an increase of the angle of slope, as also thorough drainage, would save future labor and expense in maintenance, but how rarely was there a chance to put such knowledge into actual practice. A plea for it would not have availed much with our financial managers, who seldom had money in advance of present urgent requirements.

The slopes would wash and completely fill the ditches, which the contractor would be required to clear at the last moment before getting his final estimate. But how very soon it was after his departure that the process had to be repeated, and so on almost continuously.

If we had seriously suggested to our boards of managers the importance of giving ample width to the slopes, to be immediately followed by sodding them, we would have been laughed at; and had the proposition been tolerated and the work attempted, we would, in all probability, have very soon found ourselves out of employment, for the cost would have been overwhelming, and our railroad companies would have been bankrupted sooner than so many of them have been.

All that we could do in earth excavation was to round off the top of the slope, and if it crumbled off, to endeavor to prevent its falling into the ditches.

It was deemed good practice in such cases to make a berme or bench along the slope at about the height of a platform car, so that the berme should catch the greater part of the wash from the slopes and prevent its falling into the ditch, holding it at this higher level, whence, at convenient times, it could be more economically handled and loaded directly with the ditching train.

If, in the case of our older roads, we have now reached the time when the slopes having been widened by natural or special causes, we can with comparatively little labor dress them off and plant or sod them, we are coming to a very desirable condition, but to one that could not have been attained at the outset.

It seems to me that even now it would be a simple impossibility in this country to grade a new road and talk to the authorities about sodding or planting the slopes.

With regard to the matter of drains at the top of the slope in exca-

vation, my own experience does not follow that which one speaker referred to : that ditching at the top of the slope is always injurious ; I have found quite the contrary. Ditching at the top of the slope where there is much drainage into the cut I have found the only remedy from serious trouble. If the soil is of a character which is readily permeable and the water can come down through, we must construct the drain with paving or boxing in order to carry the water off and prevent its cutting in. The draining of the top of the slope I have always considered as very important; I never deem the work so poor but that we can afford that. Draining at the bottom is also very important.

D. J. Whittemore, Past President Am. Soc. C. E.—I partly agree, and perhaps may quite agree, with our Past President, Mr. Cohen, that it is not always policy to have surface ditches at the outside, and in some places it may be policy to have tiles. In the region in which I work there is hardly any instance where it would be policy to have those ditches outside and above the slope. The earth is easily saturated with water, and it is quite difficult to compel road repairers to attend to such ditches.

About railway companies not permitting the engineer to employ the devices I have mentioned in this little paper, I believe that, if the engineer would properly assert himself, in many instances the expenses of sodding these slopes and forming them would be saved during the first year of operation ; preach that to managers, and I believe they would act upon the advice. I think that is perhaps where our difficulty has arisen, that we have not gone to the president and the active directors of railways and talked as we should. I find no difficulty with the directors of my line in this very matter ; of course, they have had long experience, and as the manager of our line in one case remarked: "We must do that on our next work ; if we had put it on our last 200 miles of road we would have saved thousands of dollars." That is the fact of the line with which I am connected, and I am pretty confident that if the younger, and older members too, talk this up with the companies, they will succeed very often, and, at the same time, save nearly the entire expense of such work during the first year of operation of the road.

Desmond FitzGerald, M. Am. Soc. C. E.—It may gratify Mr. Whittemore to know that in Massachusetts we have built embankments as he suggests in this paper. I believe the ideas advanced are practical. Materials of which embankments are made differ, however, so widely, according to the section of the country, that general rules must be applied with judgment. In New England, in order to protect the sides of embankments, it is necessary to have a good depth of loam upon the gravelly materials forming them. Sodding alone without plenty of loam is soon lost. I have often seen embankments built

under specifications which called for 9 ins. of loam. I don't know where that 9 ins. originated, but I have seen it for years in specifications. Two or three feet of loam are necessary to form a permanent sod. It may seem extravagant, but in building high embankments I have always put on as much as 2 ft. where possible. If less is put on, the grass will not hold its own through droughts.

Mr. Whittemore.—While it has been about 45 years since I had my first division in New England, I recollect well the distinctive nature of the soil; it was sandy gravel, and it would be quite an undertaking on that line of road to maintain seeding. It could be done, of course, but there was not that necessity for it in a soil of that dry nature as there is in the vast regions of the West, where there is a clay of loam, and, I venture to say, that in 6 000 miles of road I have in mind there are not over 100 or 200 miles where you would have to do very much to produce soil on slopes of cuts that would maintain the growing of grass. If such places as that are found, I should suggest always sodding. Sod is easily to be procured, and by proper staking I have found very little or no difficulty in its continued growth. There is a distinction between the various portions of our country; what will work in one locality will not in another. In the large regions of the West, and in the prairie country, I can see no difficulty in maintaining sod upon the surface of the slopes.

Benjamin Reece, M. Am. Soc. C. E.—In regard to rounding off the top edges of embankments as here advocated, I will say in the work of cutting down grades on the Lake Shore and Michigan Southern Railway, in my charge from 1881 to 1887, the advantage and economy of the proposed change was strikingly illustrated. In lowering many of the cuts the work was done by steam shovels, and where the position of curves would permit, the original track was left undisturbed to carry the traffic, while the new roadbed was excavated close by the side of the old one to the proper depth required for the new grade.

To avoid delays which the purchase or condemnation of additional right of way would entail, these excavations were kept as close to the original track as the safe carrying of trains thereon would permit.

These improvements were of such magnitude as to frequently consume several months' time before their completion, and in the earlier days of the work much trouble and considerable expense was experienced by the top edges of the cuttings breaking away and sloughing off from under the ends of the ties of the track. Night and day watchmen patrolled the track in advance of the trains and the necessary repairs were kept up. As soon as this tendency became apparent the workmen were required to round off the exposed top edge of the roadbed, and from that time on no further trouble was experienced. The advantages thus derived under extreme conditions described very

clearly points to the scientific basis and practical value of the suggestions made by the author of the paper.

The form proposed is the one which the trackman must ultimately give the slopes of his embankments and excavations in order to make them stable. If, as has been suggested, the slopes would of themselves assume the form proposed, there would be little trouble, but they do not, for usually the earth sloughs off in very considerable masses, filling up the ditches of the cuts and reducing the top width of embankments, calling for constant labor at considerable cost to clean out the one and to reinforce the other.

There is little doubt in my mind that for every yard of earth handled at small cost in construction to perfect the form of excavations and embankments as indicated by the author, the trackmen will be saved the necessity of handling many yards at high cost in the work of repairs.

Railways are built to be operated, and the engineer builds best who has due regard to the necessities of maintenance as well as of traffic.

By preventing the first tendency of the earth to move, which in ordinary soils is by no means difficult, much money and labor can be saved.

As further illustrating this question, I will say that in raising the embankments for the changes of grade and second track, it was found that in the higher fills with practically the same material the quantities of earth required for a given raise showed quite a variation with no apparent cause. A study of this feature soon revealed the fact that where the ends of the slopes terminated in the old ditches, the movement out was prevented, and the earth of the slopes was compacted upon itself, affording in the aggregate a considerable saving in amount of material moved, as well as giving a better consolidated and more stable embankment. After this observation a small footing trench was dug along the marginal edges of the foot of embankments and the little extra labor of so doing was repaid many fold.

In preparing the site for the new passenger station of the Lake Shore and Michigan Southern Railroad at Toledo in 1886, it was necessary to widen the excavation at that point, which was from 20 to 25 ft. in depth. The first 6 or 7 ft. from the surface was a friable yellow clay, the rest of the depth was through a tough blue clay which was rendered more or less unstable by the presence of sand pockets and seams.

The original cut, notwithstanding the free use of drain tile, had always given more or less trouble and at one time necessitated the removal of a slide containing some 200 carloads of earth. The work of excavation was done by steam shovels which left the sides almost perpendicular. As the top slope when formed constituted one line of a street running parallel with the railroad, its stability was

a question of prime importance. In shaping this slope a small V-shaped trench about 1 ft. in depth was cut along where the foot of the slope would fall, the perpendicular walls of the cut as left by the steam shovel were broken down, forming the slope, which was allowed to settle and the small V trench holding the toe of the slope from pushing out, it soon consolidated, when drains of cobble stones were laid obliquely down the face of the slope, which was then seeded to grass, and up to the present time no further trouble has been experienced. When tile drains were used a slight movement of the face of the slope would tend to destroy the connections of the tile drains, leaving the water to percolate through the cut, which caused more or less frequent slides, but with a good body of cobble stone forming the drains such movements of the slope caused a slight attenuation, but did not destroy the continuity of the drains and the conditions of good drainage were preserved.

The character of the materials handled has, of course, much to do with the methods which should be employed; nevertheless, as a general proposition, the methods advised in the paper can be defended and sustained as being more efficient and less costly than those which now prevail.

J. M. Knap, M. Am. Soc. C. E.—In the matter of sodding, if the course pursued by the Ogdensburg and Lake Champlain Railroad Company in the construction of their road were generally adopted, it would be a good thing. This company had incorporated in its contracts that the slopes of cuts should be sodded, and withheld part payment until it was done.

One piece of their work (a cut some 20 ft. in depth and about one mile in length), done 40 years ago, was sodded at the time, and is the admiration of all who pass over the road; the slopes are in good shape to-day, and have been maintained at little or no expense. The extra cost to the company at the start was trifling, although it must be admitted that the contractor did fail.

Mr. Crowell.—The value of such luxuries as sodded banks is manifested on all roads that can afford to make a choice between the two methods. The practice has generally been settled by the crude test of first cost, but the tendency now is toward the crucial test of maintenance charges. I quite agree with the proposition stated, that many roads could not be built if this expense were added to construction account; there is not money enough in hand in building many new roads to go to such expense; but that has nothing to do with the best practice. Makeshifts are often necessary in new construction; but if there is money enough in hand to secure it, the permanent character secured for embankments and cuts at the earliest possible moment is an element of economy in the operation of the road. The sodding of a bank, which looks like an ornament in a well-kept cut, is not a luxury at all, but a money-saving contrivance.

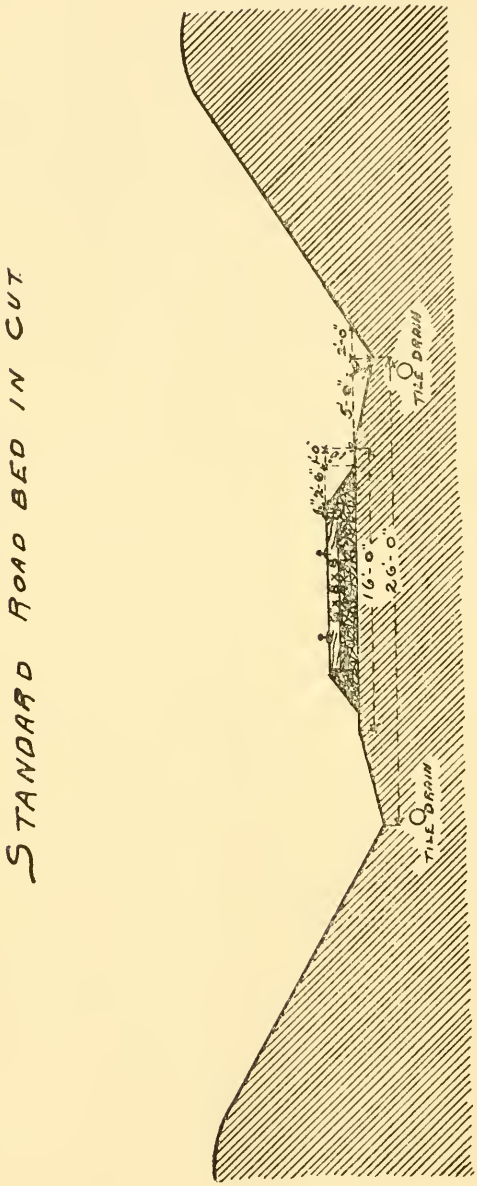
In regard to the question of ditches at the tops of slopes, my proposition was misunderstood; I should be the last to say that the ditch was not necessary there. What I did say was that the presence of the ditch on the top of the slope was apt to produce a saturation of the ground, making it all the more desirable to flatten the top of the cut. It is impossible to avoid such ditches, but still they are often used to too great an extent. Water is not infrequently carried along them which ought to be taken down to the track level by the shortest path, or be otherwise disposed of, so as to get it away from the slopes. Slope drains, with paved channels which carry the water directly down the slope, are often used with good results. Established railroads, when extending or widening out, increasing the number of tracks, resort to sodding at the earliest possible moment, chiefly to reduce the maintenance charges, and that should be the object in every case; although it is, of course, impossible to secure, in the first year of a railroad embankment, the permanence which will come in time.

J. F. Wallace, M. Am. Soc. C. E. (by letter).—If the ideas advanced by Mr. Whittemore had been put into practice years ago, the result would have been a saving of hundreds of thousands of dollars to railroads in the central and western portions of the United States. The past and present practice of making the cross-section of railroad excavation and embankment conform to the theoretical lines laid down by the earlier engineers has so far given expensive and unsatisfactory results.

The writer has known cases where it has required as great an expenditure of money to obtain and maintain a good roadbed through excavations as it originally cost to make the excavations, due to the sloughing-in of the sides of the excavations, the filling up of the ditches, and the imperfect drainage caused thereby; necessitating, not only the expensive method of cleaning out surface ditches by the use of work-train service, but also a waste of money in keeping the track in proper condition while the work was under progress.

Most of the railroads constructed in the south and west have rarely been fully ballasted at the time the work was originally done, the ties being laid on the surface of the ground, and surfaced slightly with ordinary soil. After the first few rains the original ditches would be filled with the wash from the slopes or the sloughing in of the sides of the cuts. During the wet season it would be almost impossible to ditch the cuts, as the material in the ditches would be a soft slush; frequently the track would be blocked up by using extra ties at a cost of 50 cents apiece. Sometimes the tracks would disappear entirely below the mud, and the writer knows of one case in which two additional tracks were laid, one after the other, on top of the original track, in order to maintain traffic.

The form of cross-section suggested by Mr. Whittemore would


I.C.R.R.
STANDARD ROAD BED IN CUT
TILE DRAIN
16'-0"
26'-0"
TILE DRAIN
2'-0"
SECTION OF STONE OR COARSE AND LOOSE NON
CEMENTING GRAVEL BALLAST IN CUT

largely prevent this, but not entirely so of itself. This form of cross-section used, however, in connection with drain tile as suggested would give good results. The systematic use of drain tiles in earth excavations is the best remedy for the sloughing in of the sides of the cuts and the filling up of the surface ditches.

There are a few roads, however, in the central and western portions of the United States where drain tile has been systematically used. In 1892 the writer commenced on the Illinois Central Railroad the systematic use of drain tile in excavations, and with the most satisfactory results, and it is the intention to pursue the use of tile until all the cuts that are wet or springy have been thoroughly tiled. The minimum size of tile used is 6 ins., and the maximum 12 ins. Several long cuts that were tiled in 1892, where the grade of the track was one-half of 1%, and the cuts from 3 500 to 4 500 ft. in length, the 12-in. tile was used for a few hundred feet from the mouth of the cut, and was then reduced as the work proceeded toward the summit from 12 to 10 and 8 ins., and then to 6 ins. in diameter.

The cross-section suggested by Mr. Whittemore will be of little avail unless sodding is done at the time the work is constructed; and the writer would also suggest a modification of his cross-section as per the diagram on page 264.

As an illustration of the expense entailed by not taking proper means to protect the slopes and provide for subdrainage during the period of construction, the writer would refer to one division of road that was constructed five years ago. Upon 50 miles of one section of this line, the writer now has two ditching trains which will be engaged for five months in cleaning out the surface ditches, which, in his opinion, would have been avoided if the work of construction had been carried out on the lines suggested in Mr. Whittemore's paper.

Since reading Mr. Whittemore's paper, the writer has adopted the cross-section shown on diagram as the standard cross-section for new excavations on the Illinois Central Railroad. A cross-section of similar form, but with a slope of 2 to 1, has been used by the Illinois Central Railroad Company between Dubuque and Sioux City, and on the branches in Iowa. The use of this cross-section was due to the existence of a large number of shallow cuts that only needed surface ditching; it was also desirable to have a curved form of cross-section and flat slope in order to prevent the accumulation of snow. The old excavations were worked over with ordinary drag scrapers. This work was done at an approximate cost of 10 cents per cubic yard, and the waste material spread uniformly over the right of way outside of the excavation. This was not only an economical way of ditching the excavations, but the using of the flat slope and the curved cross-section gave the wind a chance to sweep the excavations clear of snow, and prevented the deposit of drifts. This plan was

adopted two years ago, and has given satisfactory results, both in the ditching of the cuts and in preventing deposits of snow during the winter season.

Charles H. Snow, Assoc. M. Am. Soc. C. E. (by letter).—A gentleman has spoken of the advisability of placing a layer of top soil on the slope of the otherwise composed railway embankments. It is, of course, obvious that if embankments are to be protected by vegetation, turf or seed must not alone be applied but be kept alive, and they can alone be kept alive by congenial soil, such as banks are not always composed of. There is, then, the difficulty, not alone of procuring turf or seed, but frequently top soil as well, and it would seem that if objections were raised to the cost of sod or seed, the same would be much magnified in the matter of top soil, as necessary as the others. Sufficient top soil would often form a large proportion of embankments, so that in some parts of the country the embankments would be largely composed of material which must be brought from 5 to 500 miles. Again, the wide strip of our Western Continent, crossed by all of the overland routes in which vegetation is not possible without irrigation, must be encountered. If the suggestion of the author of this paper were to be applied generally, instead of locally, as he intended, some provision would be needed for irrigating such tracts.

Those of us who visited Sandy Hook last January noticed some places in which sod did not entirely cover embankments, but squares of it were placed alternately so that the whole appeared like a checker board.

Mr. Whittemore (by letter).—Further remarks of the writer will be as brief as the paper itself.

Of course there are localities where, during initial construction, it will not be reasonably practicable to secure and maintain a growth of sod along slopes, particularly where the line traverses regions destitute of soil, and where embankments and excavations are of clean gravel and sand, and it is equally true that in such localities generally little trouble is experienced in securing stability of slopes as affected by water. The writer claims that his suggestions apply with marked force to those extensive regions through which lines are built, having soils more or less rich, and which are in many instances several feet in depth, and in which the unprotected slopes become mud producers during and after storms. The necessary width of excavations at formation level depends in degree upon the depth and kind of ballast used. The writer's sketch indicates a section found serviceable where fine gravel is used; when coarse gravel, broken stone, or calcined gumbo is used, a different form of section is advised.

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(Vol. XXXII.—September, 1894.)

THE TEQUIXQUIAC TUNNEL.—DISCUSSION ON PAPER No. 725*.

By DON LUIS ESPINOZA.

Ever since Cortes established the present city of Mexico on the site of the ancient Aztec Venice the problem of the drainage of the valley of Mexico may be said to have occupied the attention of its inhabitants. The projects for dealing with the difficulty have been numerous, and very large amounts of money have been spent and much work done since the time referred to; work which in some cases has been partially successful, or which, at any rate, has tended (aided by the changes in the rainfall of the district, contraction of the area of the lakes, etc.) to modify considerably the old conditions and to simplify somewhat the problem.

Among the first projects which were advanced at the commencement of the 17th century, was that of engineer Henry Martinez, which, having been approved and started, served to commence the work known as the Virreyes; this was at the time when there was peace in Mexico under the dominion of Spain. The plans of Martinez were

*"Tequixquiac Tunnel, Valley of Mexico." By Albert Johnstone Campbell and Frederick William Abbot, Assoc. M. Am. Soc. C. E. *Transactions*, Vol. XXXII, page 171.

entirely different from those which are now being carried out, and it is not necessary to follow the different branches of said plans, but only to say this much : that they consisted at first in plans for a tunnel discharging in the neighborhood of the town of Huehuetoca, for which, on account of the falling in of the roof, an open cut, which is now known as the cut of Nochistongo, was substituted. This work only served to deviate from the narrow enclosed basin called the Valley of Mexico a part of the water which the rains precipitated into it.

Thus this tunnel, on account of its having been started at a level higher than the bottom of the valley, did not solve the problem of drainage.

The plan which is now being carried on, and known as the Tunnel of Tequixquiac, is a complete solution of this difficulty, not only drawing away from the valley the waters which run into it and thus flow into the city of Mexico, and avoiding the constant danger of inundation to which it has always been exposed, but at the same time arranging a plan by which it will be possible to drain the city thoroughly, giving a sufficient flow to the sewers which will be constructed to perfect its sanitary drainage.

The plans for the Tunnel of Tequixquiac were also suggested in the 17th century by Simon Mendez, a miner, and were approved and started after the tunnel built by Martinez had fallen in, but were soon abandoned on account of excessive cost. Later, in 1774, the plan of the Tunnel of Tequixquiac was carefully studied by the learned Don John Velazquez of Leon. The problem was again studied by Lieutenant Smith, of the Army of the United States, in 1848, who was authorized by the Drainage Board of Mexico to make such investigations ; and, by order of the meeting of the Drainage Board of the city of Mexico in 1855, was again studied by Engineer Don Francisco Garay. Still later, during the empire of Maximilian, the present project was taken up by a special commission of engineers, and the work started. Several of the shafts on the line of the tunnel were excavated to a considerable depth, and at the same time work was commenced on the construction of offices, etc., and the erection of machinery. The fall of the empire paralyzed the work for some months, but the Government of the Republic commenced it again, going over the plans once more, ratifying them, and deciding that the present line of the tunnel was the most convenient.

After having finished, under the administration of President Señor Jaurez, in the years 1868–71, a large amount of work, such as deepening the shafts and installing machinery, as well as the construction of the open cut at the outlet of the tunnel, about 2 000 m. long, with a maximum depth of 27 m., the work was stopped on account of the general disturbance in public matters, and was not again started until 1885, when a special commission or drainage board was formed by General Diaz, and work under the direction of the writer, who was the government engineer, was again commenced. From 1871 to 1885 all that was done was to preserve the work which had been completed, and to take care of material, etc.

In the opinion of various engineers the different projects which have been designed for this work show a tendency towards too great size in the dimensions of the cross-section of the tunnel ; at the same time it was peculiar that in all of these plans there were no two alike, which necessitated a new calculation each time. This was finally made by the writer, who determined the quantity of water which it was necessary to handle for the drainage of the valley of Mexico, which quantity he places at 17½ cu. m. per second, and also determined the dimensions necessary to make the tunnel sufficiently large to handle this quantity; and he it was who ultimately designed the section which is now being built.

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(Vol. XXXII.—September, 1894.)

FRICTION ROLLERS.—DISCUSSION ON PAPER No. 722.*

By J. B. JOHNSON, M. Am. Soc. C. E., and A. MARSTON, Assoc. M. Am. Soc. C. E.

J. B. JOHNSON, M. Am. Soc. C. E. (by letter).—This is the most valuable contribution to our knowledge of the strength, friction and wear of metallic rollers that has come under my observation. Professor Marston has rendered us a good service in his elaborate analysis of the distribution of stress in a metallic roller, but I would prefer to see the development of the subject based on the distributed stress which obtains in practice rather than upon a concentration of stress on a linear element of the roller, as has been assumed in the paper. I see no advantage, for instance, in the development of formula (15), giving the area of contact on the assumption that the load is wholly concentrated on a mathematical line. This method of concentrating the load would produce an indented roller and plate, with an infinite intensity of stress along the loaded line. The assumptions involved in equation (15) are, therefore, purely hypothetical and far fetched, being not at all applicable to

* "Friction Rollers." By C. L. Crandall, M. Am. Soc. C. E., and A. Marston, Assoc. M. Am. Soc. C. E. *Transactions*, Vol. XXXII, page 99.

the determination of the area of contact, and might therefore be omitted from the discussion. Immediately following this development, however, the author gives the result of a development of the theoretical area of contact when the true distribution of stress is used. The mathematical analysis involved in this result might well have been inserted in the paper in place of the conventional assumption involved in formula (15). A rational analysis for determining this theoretical area of contact has never yet been published, so far as I am aware.

It is also unfortunate that no record has been given of the areas of contact corresponding to the experiments plotted on Plate XVIII. I am inclined to give great weight to these experiments, as they seem to have been made with adequate care and with intelligence. If the author of the paper could give us the law of the areas for increasing loads when the diameter remains constant, and also the law of the areas for constant loads with varying diameters, he would add largely to the value of his paper, so far as the theoretical analysis of the problem is concerned. He has, however, given us no information as to these areas, and perhaps they were not taken.

So far as a working formula is concerned, however, for the strength of a metallic roller, the results plotted on Plate XVIII seem to be entirely satisfactory. They show conclusively that the crippling load on a metallic roller varies directly with its diameter. This conclusion is quite independent of any theory of stress distribution, and would seem to warrant the use of a working formula like that given in equation (17), in which the working load per unit of length of roller is some constant multiplied by the diameter of the roller. So far as practical use is concerned, this is the main question, and the paper would seem to be conclusive on this subject.

I will take the liberty of adding here some results of tests for determining the area of contact between locomotive and car wheels and rails obtained by me five years ago, when the subject of "Wheels and Rails" was so prominently before this Society. A section of a steel-rimmed locomotive driver 44 ins. diameter and a section of a 33-in. diameter cast-iron car wheel were procured and mounted in a 100 000-lb. Riehlé testing machine. Short sections of steel and iron rails were also procured and placed in the machine, so that the wheel-treads rested upon them in a normal position. They were then loaded with 5 000-lb. increments, from 5 000 to 60 000 lbs., the area of contact

being measured after each loading. These actual areas of contact are given in Plates XXXIX, XL and XLI, where they are shown to a scale one-half the actual size, thus making the areas one-fourth actual size. In Plate XLII these areas are plotted for both the 33-in. and the 44-in. wheel.

The surfaces of the wheel-treads and also of the tops of the rails were highly polished, so as to become good mirrors, before the experiments were made.

The areas were obtained by marking with wet chalk the surface of the rail and rubbing it down with a moistened finger and allowing it to dry. This gave a whitish appearance to the surface, with no appreciable thickness of film, and the actual area of pressure contact was clearly shown by a slight discoloration of this surface. A pencil line was passed around the border of this contact area, and then the area copied on tracing paper. The surface was then cleansed and examined for permanent distortion, and prepared for another loading.

No permanent distortion was noted upon either rails or wheels at the contact surface up to the 60 000-lb. limit. At this loading, however, the web of the rail was observed to take a permanent set.

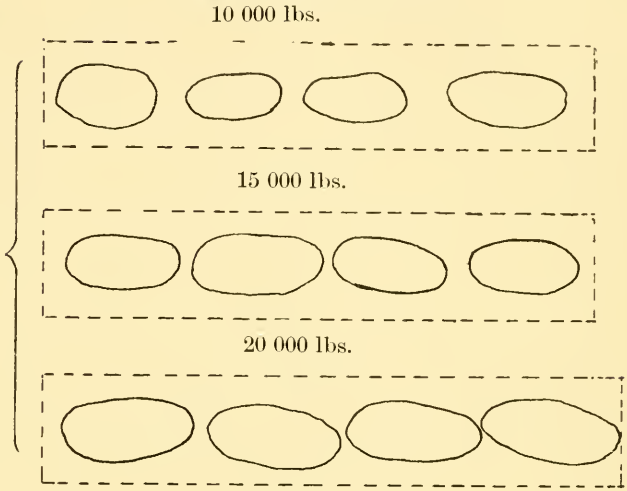
The most remarkable feature of these tests would seem to be the law of increase of area with increasing loads, as shown in Plate XLII. These areas plot practically upon a straight line through the origin, indicating that the area is directly proportional to the load. This being true, it must follow that the load divided by the area of contact, or the average stress per square inch over the area of contact, is a constant for all loads. This constant is something over 80 000 lbs. per square inch, but the distortion or compression of the surface at the center of these areas of contact is just twice the average distortion over the area, and, since the loads seem to be within the elastic limit of the material, it follows that the intensity of stress at the centers of these areas of contact were twice the average intensity of some 80 000 lbs. for the steel driver upon a steel rail, or that the maximum intensity of stress at the centers of these areas was for steel upon steel 160 000 lbs. per square inch. For the chilled cast-iron wheel 33 ins. in diameter this maximum intensity was still greater as the area was less.

These areas were obtained by placing two cylinders in contact, their axes being at right angles. The volumetric distortion for each

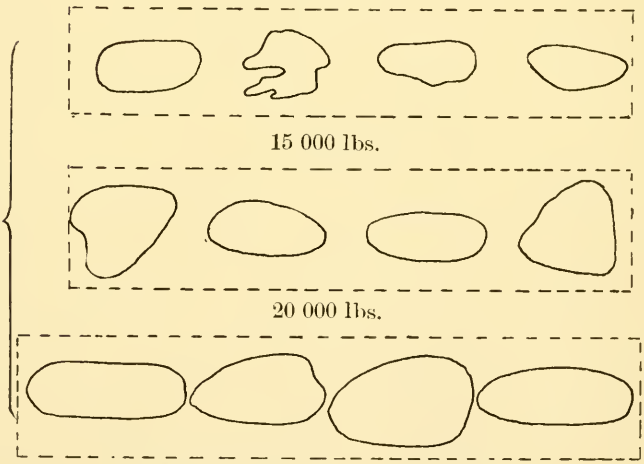
IMPRESSIONS ON WORN IRON RAIL. TOP RADIUS, 11 INS. FULL SIZE.

Direction along the Rail.

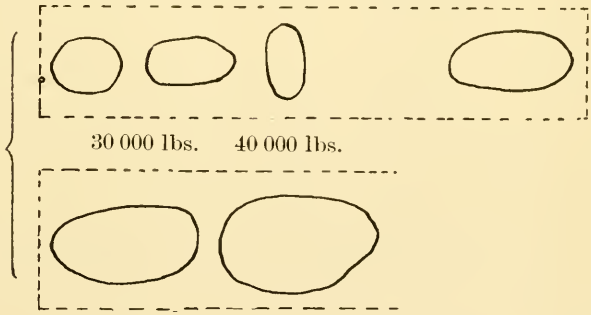
Steel Driver, 44 ins. diam. Flat tread.



Steel Driver, 44 ins. diam. Much worn. Rad. groove 10 ins.

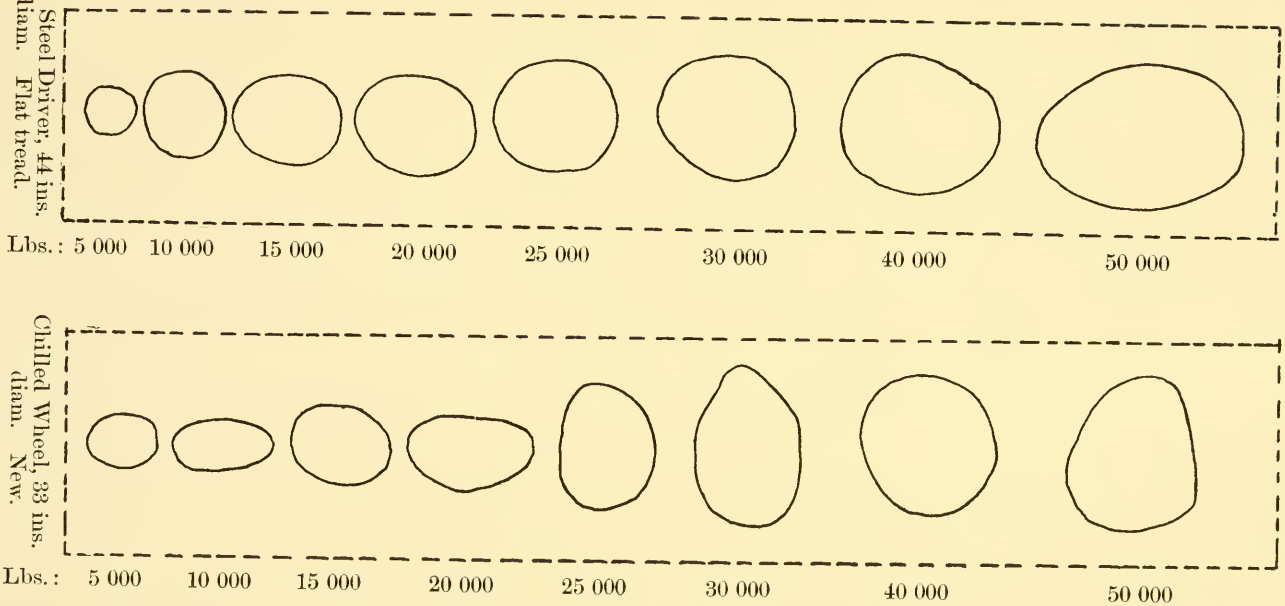


Chilled Wheel, 33 in. diam. New.



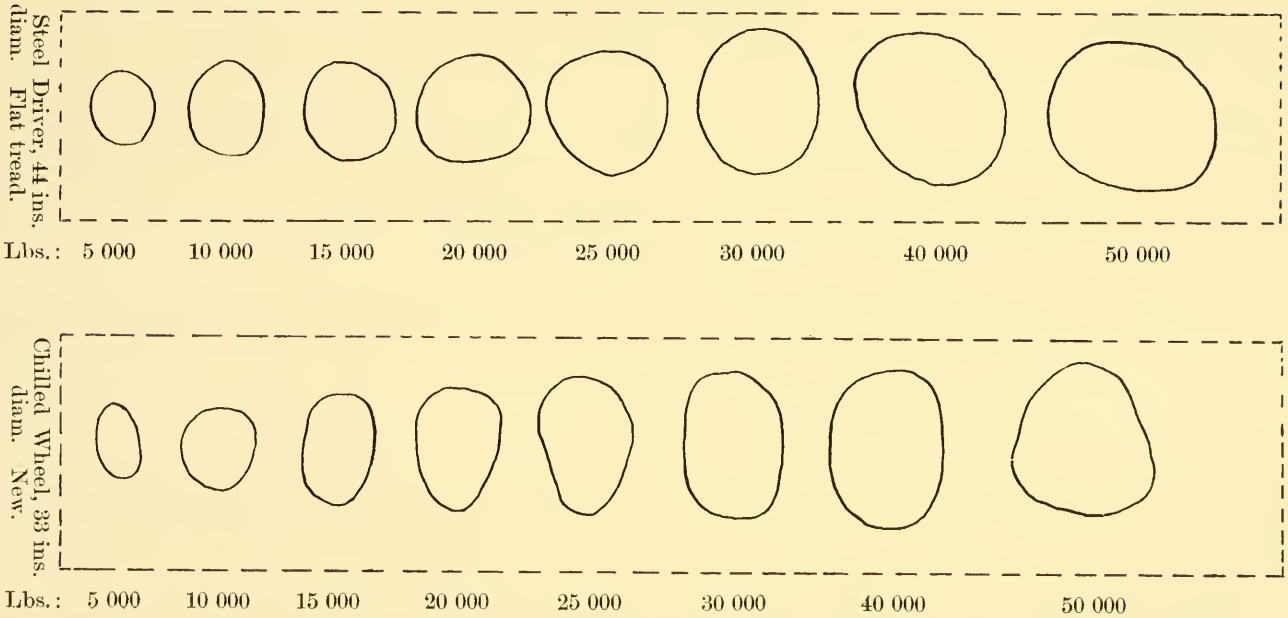
IMPRESSIONS ON 52-LB. STEEL RAIL. TOP RADIUS, $13\frac{1}{2}$ INS. FULL SIZE.

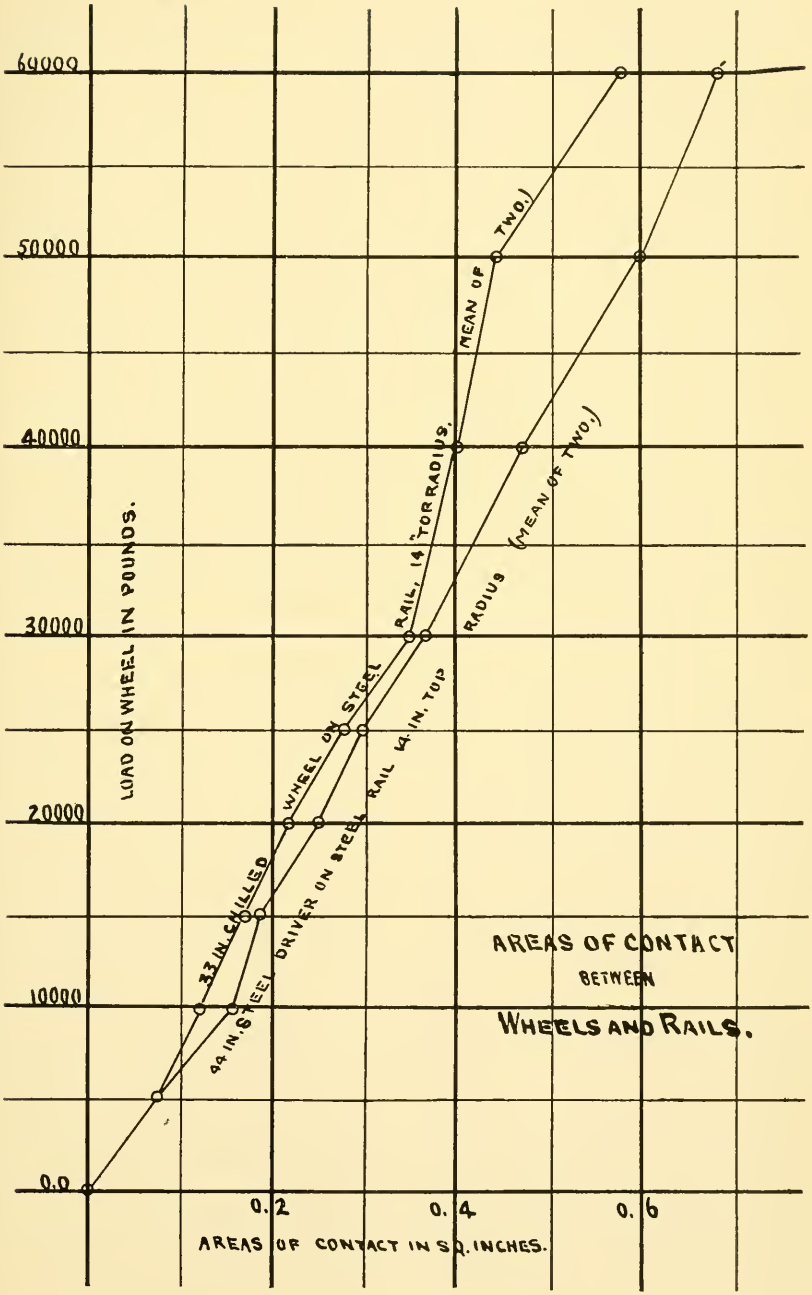
Direction along the Rail.



IMPRESSIONS ON 75-LB. STEEL RAIL. TOP RADIUS, 14 INS. FULL SIZE.

Direction along the Rail.




60000
50000
40000
30000
20000
10000
0.0
0.2
0.4
0.6
LOAD ON WHEEL IN POUNDS.
AREAS OF CONTACT IN SQ. INCHES.
MEAN OF TWO.)
RAIL, 14" OR RADIUS.
RADIUS (MEAN OF TWO.)
WHEEL ON STEEL
RAIL 14 IN. TOP
33 IN. CHILLED
44 IN. STEEL DRIVER ON STEEL RAIL
AREAS OF CONTACT
BETWEEN
WHEELS AND RAILS.

of the surfaces in this case is fairly represented by the segment of a paraboloid. A property of the segment of a paraboloid is that the maximum ordinate is twice the mean ordinate, or, in other words, the volume of the segment is one-half the enclosing cylinder. This fact authorizes the statement made above, that the maximum distortion at the centers of these areas of contact is twice the average distortion, and hence the maximum stress is twice the average intensity of stress as above stated.

I have withheld these observations from publication, thinking I might be able to find a rational analysis of the problem explaining the distribution of stress and this law of area of contact. If Professor Marston will develop the analysis leading to his conclusion concerning the area of contact for a cylinder upon a plane for distributed stress as given by him on page 122, following equation (15), and will then adapt the analysis to two cylinders in contact, he will have furnished the requisite theoretical explanation of the areas given in Plates XXXIX, XL and XLI, and may be able to explain the law of variation of area of contact with load, as shown in Plate XLII. A simpler case to work out would be that of a sphere upon a plane, and the analysis of this case would doubtless be very nearly applicable to the case of two cylinders crossing each other. The analysis of these two cases, namely, a cylinder upon a plane, and a sphere upon a plane, considering the stress distributed over the areas of contact according to the laws of the parabola and of the paraboloid, with due allowance for the distribution of the stress through the body of the roller, according to the laws already determined by Professor Marston, would, I believe, show a close agreement between the computed and the actual areas of contact and would serve as the last word on this subject from the mathematical point of view. As the paper stands, however, it contains no such theoretical analysis. I venture to hope that Professor Marston will supplement his paper with the true analysis of this problem.

A. Marston, Assoc. M. Am. Soc. C. E.—A copy of the paper in the "Physical Review," referred to by Mr. Hutton,* was sent to the Society some months since.

The formula quoted by Mr. Hutton from Résal is the particular form of the Grashof formula referred to in this paper at the commencement of the discussion of formula (14). The assumption that the value

* *Transactions*, Vol. XXXII, page 127.

of the maximum pressure at the elastic limit is 30 000 lbs. per square inch for steel on steel may be compared with Professor Johnson's conclusion, arrived at by actual measurement of the areas of contact, that the maximum pressure in the case he cites was 160 000 lbs. per square inch.

With regard to the assumption made in this paper that the stresses and displacements in plates and rollers are, except very near the area of contact, the same as if the loads were applied along a line instead of over an area of contact, it may be said that this assumption is entirely similar to the one always made in the common theory of beams, that the stresses are the same as if the concentrated loads were applied at mathematical *points*. The correctness of this assumption was enunciated by Saint Venant, has been proved by Boussinesq, and may be considered as well established.

The writer is satisfied that, owing to the way in which the load is distributed over the area of contact, the forms of the surfaces of the roller and plate under strain will be so nearly the same as indicated by equations (5) and (11) up to the very edge of the area of contact, that the use made of the above principle in deriving a correct *form* for the empirical equation (15) for the area of contact is perfectly legitimate. This conclusion was strengthened by the fact that Professor Johnson has derived this equation empirically from the results of the experiments of Professors Crandall and Wing and that his values for the constant K are nearly *proportional* to the $\sqrt{\frac{c_r + c_p}{\pi}}$ of equation (15).* Moreover the writer checked this assumption by computing the value of x for which $\frac{dy}{dx}$ for the plate equals $\frac{dy}{dx}$ for the roller (*i. e.*, at the edge of the area of contact), for the common assumption that the stress is distributed over the area of contact according to the law of the parabola. The result of this analysis was given in the paper, but the analysis itself omitted, because complicated, and because we have no knowledge that this distribution of the stress is the true one. The analysis, however, is presented here, at Professor Johnson's request, as follows:

The assumed distribution of stress is $G = \frac{3}{4}\frac{W}{a}\left(1 - \frac{x^2}{a^2}\right)$, where G is the stress at any point of the area of contact, and the other sym-

* See "Framed Structures," page 277.

bols are the same as those used in deriving equation (15). From equations (5) and (11) it can be shown that the *variable* part of the vertical displacement at a point x_1, on the surface of either plate or roller, caused by the forces $G\ dx$ applied at $+x$ and $-x$, is $d\ v = -\frac{c}{\pi} G\ dx \log. (x_1^2 - x^2)^2$, where $c = \frac{(1-\sigma)\ (1+\sigma)}{E}$. Hence the total displacement—

$$v = -\frac{3\,c\,W}{2\,\pi a}\int_o^a \left(1 - \frac{x^2}{a^2}\right) \log. (x_1^2 - x^2)\ dx, = -\frac{3\ c\ W}{2\ \pi a}$$

$$\left[x \log. (x_1^2 - x^2) - 2\ x + x_1 \log. \frac{x_1 + x}{x_1 - x} - \frac{x^3}{3\,a^2} \log. (x_1^2 - x^2) + \frac{2}{9}\frac{x^3}{a^2} + \frac{2\ x x_1^2}{3\ a^2} - \frac{x_1^3}{3\,a^2} \log. \frac{x_1 + x}{x_1 - x}\right]_o^a$$

$$= -\frac{3\ c\,W}{2\pi\ a^3}\Big[\ (2\ a^3 + 3a^2\ x_1 - x_1^3) \log. (x_1 + a) + (2a^3 - 3a^2\ x_1 + x_1^3) \log. (x_1 - a) + 2a\ x_1^2 - \frac{16}{3} a^3.\Big]$$

Dropping the subscripts we may compute—

$$\frac{dv}{dx} = -\frac{c\,W}{2\ \pi\ a^3}\left[\ 3\ (a^2 - x^3) \log. \frac{x + a}{x - a} + 6ax\ \right].$$

At the edge of the area of contact we have $x = a$, and the above becomes—

$$\frac{dv}{dx} = -\frac{3\,c\,W}{\pi\ a}.$$

Now $\frac{dv}{dx} = \frac{dy}{dx}$ for the plate, but for the roller we must subtract it from $-\frac{2x}{d}$ (the surface of the roller before strain being $y = -\frac{x^2}{d}$). Hence at the edge of the area of contact, where $\frac{dy}{dx}$ for the plate $= \frac{dy}{dx}$ for the roller, we shall have—

$$-\frac{3\ c_p\ W}{\pi\ a} = \frac{3c_r\ W}{\pi\ a} - \frac{2a}{d}, \text{ whence}$$

$$a = \sqrt{\frac{3}{2}} \times \sqrt{\frac{c_r + c_p}{\pi}\ Wd}.$$

(Note that a is one-half the width of the area of contact.)

The value indicated by this analysis for the constant K of equation (15) would be .000366 for the writer's experiments, assuming that $\sigma = \frac{1}{4}$, and remembering that E for this case is by measurement

27 300 000 lbs. per square inch. Prof. Johnson concluded from an examination of Crandall's and Wing's experiments that K should be .00055; but those experiments probably gave too large results, because at what the eye called the edges of the area of contact, the tallow films must have had some appreciable thickness. The following observations, just made by the writer with the 16-in. roller used in these experiments, indicate that the theoretical value of K given above is approximately correct.

Observed and Theoretical Values of Area of Contact Between 16-In. Roller and Plate.

Load per lineal inch of roller. Pounds.	Width of area over which light could not be seen between roller and plate. Inches.	Corrected width of area of contact. Inches.	Theoretical width of area of contact. $A = .000366\ \sqrt{Wd}$. Inches.
0 +	0.05	0.00	0.000
1 000	0.10	0.05	0.046
2 000	0.12	0.07	0.065
3 000	0.14	0.09	0.080
4 000	0.15	0.10	0.093
5 000	0.15	0.10	0.103
6 000	0 16	0.11	0.111

The numbers in the third column of the above table were derived by subtracting from those in the second column the area over which the light could not be seen when the pressure was zero.

Two observations for the 10-in. roller gave similar results.

In conclusion the writer desires to call attention to two points in connection with the formulas developed in this paper.

The first is that all the stresses at corresponding points in different rollers are inversely proportional to the diameters of the rollers. This may readily be proved by substituting in equation (11) the values $x = a\,r$, and $y = b\,r$ (a and b being constants independent of r) which x and y would have at such points. This fact confirms the conclusion that the safe loads on rollers are directly proportional to their diameters.

The second point is that the value of Q_p in equation (6) furnishes a means for determining what thickness of bed plate under the friction rollers at the end of a bridge will meet with sufficient exactness the common requirement of bridge specifications that "the bed plates shall be thick enough to distribute the pressure uniformly over the

masonry." If W be the load per unit of length on the roller, t the thickness of the plate, x the perpendicular horizontal distance from any point on the lower surface of a bed plate to a vertical plane passed through the axis of the roller, and Q_m be the normal pressure on the masonry at that point caused by the roller in question, then—

$$Q_m = \frac{2\ W}{\pi}\ \frac{t^3}{(x^2 + t^2)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (19)$$

The total pressure on the masonry at the point in question can be found by adding the values of Q_m for the separate rollers, but usually only the nearest one need be considered. This maximum pressure should not exceed a safe bearing value, which, however, may be larger than the one specified when it is assumed that the pressure is uniformly distributed. It might be specified that the maximum pressure should not exceed the average pressure by more than a certain per cent. Computations on this basis will be found to encourage the use of thick bed plates.

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HOISTING APPARATUS OF THE CANAL HEAD-GATES AT SEWALL'S FALLS, N. H.

By JOHN R. FREEMAN, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

These head-gates are of interest from their large size and from the comparative ease and rapidity with which they can be raised or lowered by the hand-power of one man.

They were built between one and two years ago from the designs of the writer, and have but very recently been brought into practical use, and, so far as yet tested, appear to meet the conditions with success.

Although these sluiceways as a whole are but a modest structure, not so extensive or so elaborate in finish as many others, the arrangement for lessening the friction of each gate is novel, and the gates are the largest similar gates in a single leaf with which the writer is acquainted.

They are situated at the head of a water-power canal recently constructed at Sewall's Falls, on the Merrimack River, four miles above the city of Concord, in New Hampshire.

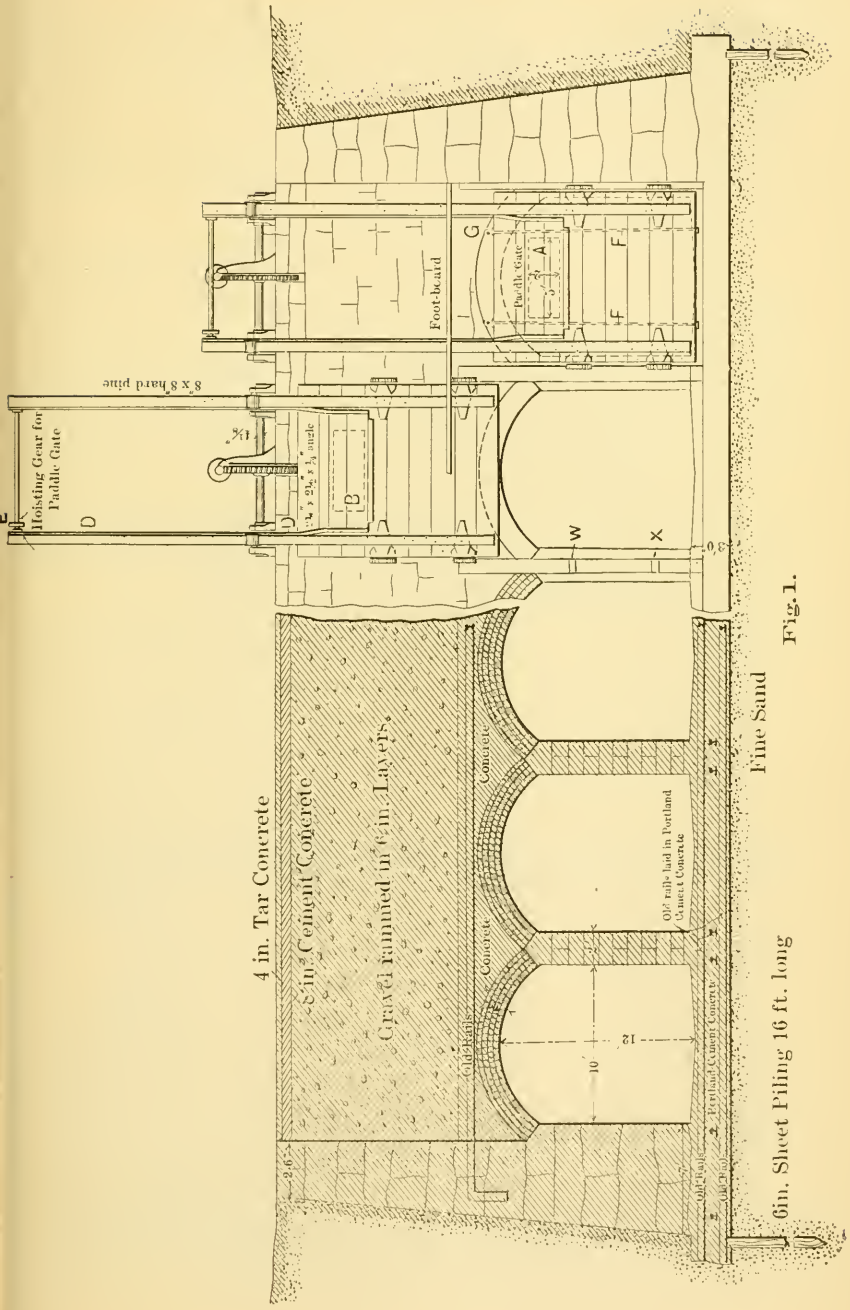

Hoisting Gear for Paddle Gate
8 x 8 hard pine
Foot-board
Paddle Gate
4 in. Tar Concrete
3 in. Cement Concrete
Gravel rammed in 6 in. Layers
Old Rails
Concrete
Old rails laid in Portland Cement Concrete
Portland Cement Concrete
Old Rails
Fine Sand
6 in. Sheet Piling 16 ft. long

Fig. 1.

They adjoin a timber crib-dam, 500 ft. long, 16 ft. high, erected from designs of Edwin F. Smith, M. Am. Soc. C. E., which is an unusually interesting example of the very best grade of rock-filled timber crib-dam on gravel bottom.

It is designed that ultimately the whole ordinary flow of the Merrimack River shall pass through these gates to furnish power on mill sites lying between the canal and the river.

The natural flow of the river at this point, reinforced by the ordinary draft from the great storage reservoirs of Winnipiseogee, amounts during the dry season of the year to about 1 000 cu. ft. per second for the 24 hours. There will ultimately be considerable night storage in the pond formed by the dam, and at the hours of maximum work, or when water is plenty and the head is reduced by back water, the draft through the gates may, perhaps, sometimes be 2 000 or even 3 000 cu. ft. per second.

The floor of the sluiceways is 10 ft. below the present crest level of the permanent dam, and the top of the archway is level with the crest line of the present flashboards.

The permanent dam may, at some future time, be increased 1 or 2 ft. in height, and possibly 3 ft. more may be added by flashboards. The greatest freshet known along the Merrimack River for the past century would flow 10 ft. deep over the crest of the permanent dam.

The canal walls are carried to a greater height above the ordinary water-level of the pond than is customary. This was done for the purpose of allowing water to be carried high in the canal during freshets, and thus offsetting to some extent the loss of power due to back water. This arrangement was suggested by H. F. Mills, C. E., under whose supervision the original surveys for the development of this power were made about twelve years ago.

Figs. 1 and 2 show the general arrangement of the sluiceways.

No ledge exists at this point, and, instead of the firm stratum of gravel which we had hoped to find at the bottom of the excavation, a pocket of quicksand was found. It was by reason of the doubtful character of the earth that the writer adopted the form of structure herein shown.

The foundation was enclosed on all four sides with tongued sheet piling, as shown in Figs. 1 and 2. This was 6 ins. thick, about 16 ft. long, or driven as far as the steam pile-driver could force it, and the top

of this piling was held so it could not spread, and thus allow the sand within to escape. Resting on this sheet piling and locking over its top was a 3-ft. floor of old railroad rails and concrete, which in turn was stiffened by the stone piers above, acting as ribs over this floor, and, as a few other steel rails were inserted as ties in the masonry above the

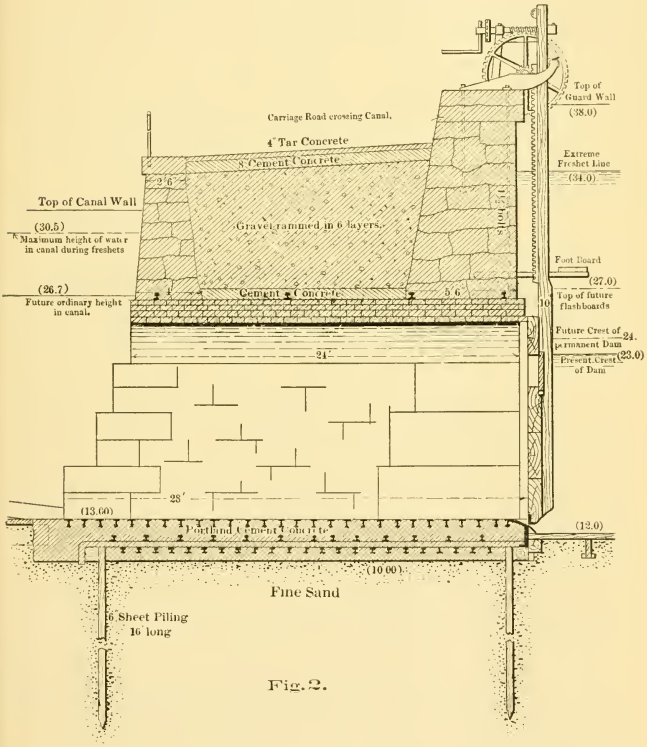


Fig. 2.

arches, the whole mass of masonry composing the sluices is expected to prove rigid as a monolith, and any settlement cracks are believed to be an impossibility.

Steel rails imbedded in concrete form a most excellent structural material for works of this class, and the writer has in several instances

felt very grateful to the engineers of Chicago for calling attention so conspicuously to its merits by their remarkable foundations.

Wing walls of cement masonry resting upon lines of sheet piling, carried down to a depth as great as could be conveniently driven, were, of course, extended out transversely to the axis of the canal for a considerable distance on either side of the sluiceway.

A plank apron, to resist scour, extends 25 ft. up stream from the gates, with 3-in. sheet piling driven 6 ft. deep across the channel at its up-stream end. A plank floor was designed to extend down stream from the concrete floor to a distance of 180 ft. from the gates. The writer did not supervise the construction of any part of the work, and has been told that this plank flooring was modified and decreased by those in charge.

The method of construction of the iron ties and girders within the concrete floor was as follows:

A 6-in. layer of English Portland cement concrete was spread and well rammed over the whole site of the sluices; on top of this a course of rails, placed on their natural bed, located 1 ft. apart on centers and extending the whole distance of 76 ft. transversely to the sluiceways. Then the spaces between were filled by a layer of concrete, and other courses of rails at right angles to the first were placed, running along under the edges of each pier. The outer ends of these rails were bent down, to hook over the guide timber of the piling and prevent any chance for the bulging out or spread of this piling; then another 6-in. layer of concrete, and then another course of rails running transversely to the sluices, but 2 ft. apart on centers; then two more layers of concrete, and then another layer of rails close to the top of the floor, laid bottom up, 12 ins. apart on centers, and flush with the flooring of concrete, which was rammed in between them.

The large proportion of iron which shows on the surface of this sluiceway floor, and the firmness with which the concrete locks in between the rails, gives a floor which it is believed will withstand almost indefinitely the scour from the swift current which at times rushes under the gates.

This mass of iron-ribbed concrete gave an excellent bearing and support for the narrow granite piers between the sluices, and the computed resultant pressure of a full pond with an empty canal, combined with the weight of masonry, falls within a base well suited to support

it, and which has furthermore a large margin, to take care of the incomputable stress from ice thrust.

The sluices are of rather coarsely dressed squared granite blocks laid in Portland cement.

Brick arches laid in Portland cement were used to cover the sluiceways, and imbedded in the masonry over these arches four more lines of old railroad iron were run, the outer ends of these being hooked down and adjacent ends strongly spliced, so that the whole masonry should be tenaciously bound together.

A comparatively small amount of cut granite was used, hardly any, except in the thin piers, the gate seats and the gearing bedstones, nearly everything being built from irregular waste stones, or "quarry grout," from the celebrated Concord granite quarries, which are about two miles distant.

It was intended, however, that much care should be taken in laying and bonding these irregular stones.

The sill on which the gates shut and the edge of which forms one blade of the powerful shears, intended not to be impeded by stray twigs of driftwood, is a massive girder-shaped iron casting, firmly imbedded in the concrete and extending under the piers. This is not machine-planed, but was cast with the foundryman's best effort to secure true form and smooth surface. The cast-iron pier faces, against which the iron face-plates of the main gates slide up and down, were also not planed, but the foundryman's skill was relied on to produce surfaces reasonably smooth and straight. At the top of the sluice the brick arch is faced by a cast-iron segment firmly imbedded in the masonry.

Money was scarce for the large enterprise in hand, and it was imperative that the design be such that the cost should be the absolute minimum consistent with safety and efficiency.

The actual cost for all of the excavation, sheet piling, old rails, concrete flooring, brick arching, cut granite, and, in short, for everything within the limits shown in Figs. 1 and 2, except the gates themselves and their hoisting rigging, and lying within the area, about 30 x 80 ft., occupied by the sluiceways proper, was about..... $15 000 00

The cast-iron pier faces for gates to slide against, sills and arch faces, including bolts, cost, for each gate erected in place, about.....	$200 00
And are included in the total on page 283.	
Each gate with its trucks, paddle-gate, hoisting rigging, gearing, pillow, blocks and fittings, all erected and complete in place, cost, about.....	700 00

All of which amounts, it may be remarked, were inside the preliminary estimates. The effort in the design was to reduce everything to the lowest terms consistent with prudence and safety, and to design the iron-work so that the pattern-maker and the moulder should do most of the manual labor upon it, leaving as little as possible for the machinist to do; and the cost, as stated above, may certainly be regarded as moderate for a work of this kind and size.

Each gate has a clear width of 10 ft., and a clear height of 12 ft., from sill to top of arch.

The feature of special interest and the sole *motif* for this paper is the method of reducing the sliding friction of the gate and bringing it within the strength of one man to lift or lower a gate quickly. We will, therefore, cull out from the dozen sheets of detail drawings enough to make the outlines of the apparatus clear, and to illustrate the method of its operation.

The writer had previously made an essay in reducing friction waste on a gate under a heavy load at the Nashua wasteway, described in a previous paper,* and for a time considered adopting there the wedge-track method here followed, but was drawn aside from doing so by certain considerations of no present importance.

The pressure which these gates at Sewall's Falls must always stand ready to carry and work under, with an empty canal and pond swollen by summer rains, amounts to about 40 tons against each gate. A prudent manager would not empty the canal during an extreme freshet, and, although the factor of safety would cover the stresses thus introduced, they may be dismissed from the present discussion.

Extended experiments by Hiram F. Mills, Civil Engineer (unpublished), have shown that values given by eminent authorities for the friction of cast iron on cast iron without any oil for a lubricant, and

* Trans. Am. Soc. Mechanical Engineers, Montreal Meeting, 1894.

repeatedly quoted in the various books of engineering data, are too low, the iron then under experiment probably not having been absolutely free from oil, and considering that we here, from motives of cost, relied, not upon machine-planed surfaces, but upon excellent foundry work, with good plumbago foundry facing to make the contacting surfaces of our slide plates smooth, it is probable that the frictional resistance to moving the gate, together with three tons for the weight of the submerged gate and its attachments, might, with an empty canal, be as high as twenty tons.

It should be possible to shut any canal head-gate with a high river on the up-stream side and an empty canal below, for if a washout or serious break occurs, how else is the flood to be quickly controlled?

Here, we may be pardoned for remarking that the existing head-gates with gearing and mountings sufficiently powerful to fill this requirement are very rare.

We made this gate go easy by carrying it upon the four cast-iron trucks as shown in Fig. 1. These trucks are 18 ins. diameter, and run on a cast-iron track formed in the same piece with the pier-face.

During the entire time when the gate is raised from its sill, the pressure is carried upon these trucks. When the gate is entirely closed, these trucks are thrown out of commission by a sloping depression of about half an inch in the tracks upon which they run, which allows the gate to drop back into close contact with the faces of the pier and sill. These wedge-like inclines in the track are shown at *w* and *x* (Fig. 1).

Suppose the gate now to be closed, and that we start to hoist it. At first it will start with no less of an upward pull than the ordinary gate, but by the time it has (by one minute's use of a long lever, inserted in the notched wheel *M*, Fig. 5, instead of the hand crank) been laboriously raised from 1 to 2 or 3 ins., the wedge-shaped incline on the rail under each of the four trucks will have brought these trucks to a firm bearing on their rails, and the face of the gate will be lifted up stream ¼ in. or ½ in. away from sliding contact, and sliding friction will have disappeared, and thenceforth the progress of the gate will be rapid and easy.

Should one fear that drift matter may lodge between the gate and the pier, and, by holding the gate off its seat, cause leakage when it is

shut, we may remind him of the powerful grinding action of the iron plates when moved under this great pressure upon the pieces of foreign matter, which would quickly reduce them to powder.

These wedge-shaped depressions of the truck rail are $\frac{4}{10}$-in. for the upper pair (at *w*, Fig. 1), and $\frac{5}{10}$-in. for the lower pair of trucks (at *x*, Fig. 1), these being so proportioned in order that no tendency to move the gate-start up stream or down stream would exist at the point where it engages with the pinion.

In other words, the gate-start swings or pivots about the pinion, when the trucks mount the wedge-shaped lifts upon their tracks.

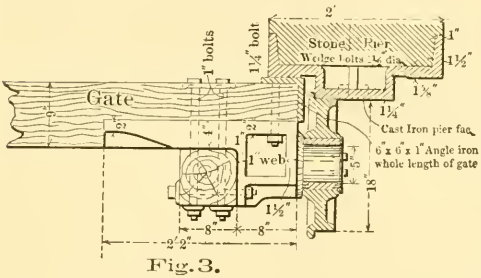
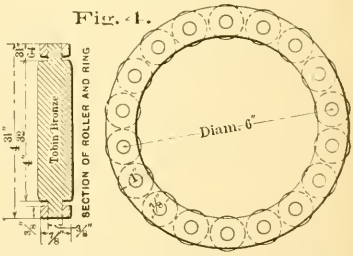


Fig. 3.

These trucks may have to carry each a 10-ton load, and their axles, to withstand so great a cross strain, must be massive and strongly secured to the framework of the gate. These axles and connections are shown in outline in Fig. 3. It will be observed that the gate-starts, so-called, or the massive handles by which the gate is pulled up or pushed down, are so connected to these axles as to distribute the stress, and that the angle iron edge of the gate gives it further stiffness.

Fig. 4.



The 5-in. axle in an 18-in. wheel would, without special appliances, in turn have a good deal of friction, being under water where oiling is impossible, and where fine sand in the water sometimes abounds. We, therefore, introduced between the axle and the truck, the roller bearing shown in Figs. 3 and 4.

These rollers are of Tobin bronze rod, 1 in. diameter, turned down to a $\frac{3}{8}$-in. neck at each end, to form a journal, which rests in a corresponding hole in a brass ring or collar, thus holding the several rollers in proper relation to each other. Their working face is 4 ins. long, and there are 18 in a nest.

Passing now to the top of the structure, the gearing is shown in

outline in Fig. 2. The worms are shown on a larger scale in Figs. 5 and 6.

Each worm was cut from a solid shaft of forged machinery steel 4 ins. in diameter. Since the worm tooth engages with a cast-iron tooth of the worm wheel, and since the short time of working will produce slight wear on the worm, we favored the weaker metal by making the wrought steel worm tooth one-eighth thinner than the cast-iron gear tooth, desiring to add all that was possible to the strength of the cast tooth, because worm wheels on gate hoists are so often found with broken teeth.

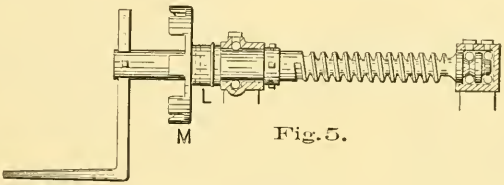


Fig. 5.

It will be noticed that the worms have a much smaller diameter than the time-honored custom of old millwrights would call for; and by so simple an expedient as reducing this diameter, bringing the friction nearer the center and getting a greater leverage on this friction with the crank, we save about half the friction found in the majority of worm-gear gate hoists.

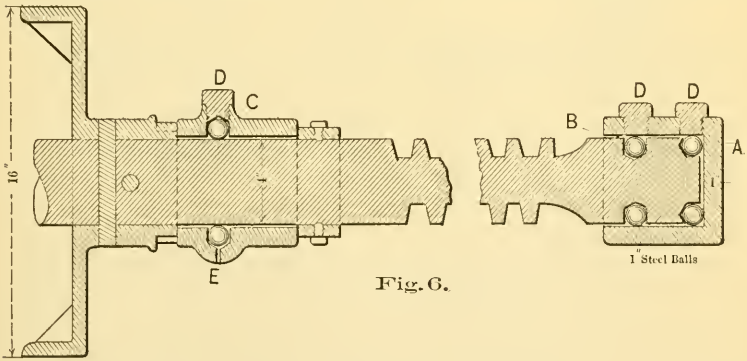


Fig. 6.

This worm has a diameter at pitch circle of gear of only twice its pitch (or more exactly, diameter of bottom of thread is $2\frac{1}{16}$ ins.; diameter at top of thread, 4 ins.; diameter at pitch line of wheel, $3\frac{1}{8}$ ins.; pitch, $1\frac{1}{2}$ ins., and angle of advance, nearly 15°), but it works

in an entirely satisfactory manner, notwithstanding its sharp angle of advance. The only trouble thus far found is that the worm wheel arms are not so stiff as they ought to be in a direction parallel to the axis. Therefore, when the worm is not properly lubricated, or when working under a heavy load, the rim of the worm wheel springs off to one side a little, under the drag of the worm, and then jumps back.

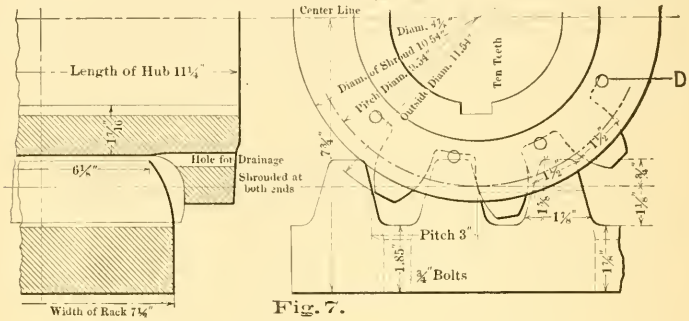


Fig. 7.

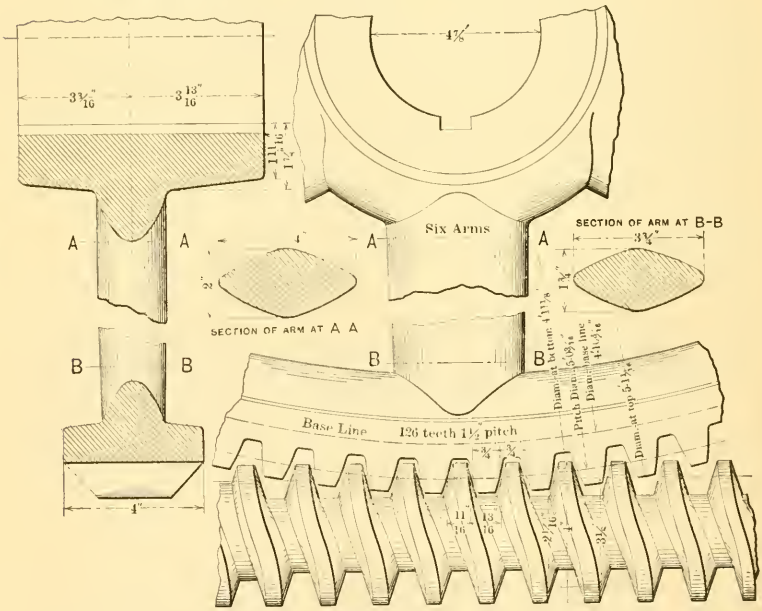


Fig. 8.

In another design the spokes of the worm wheel ought to have stiff ribs added to the rather thin section shown in Fig. 8, to prevent sidewise distortion.

To retain sufficient torsional strength with this small diameter, we had to call the worm screw thread itself into play in adding to the torsional strength of the shaft, and therefore at the crank end of the worm the screw thread starts in from the 4-in. cylinder without any notch, as shown in Figs. 5 and 6, instead of beginning the cut from a notch, cut straight around, as is more common machine-shop practice.

As a further means of relieving friction, and as a respectful recognition of the fad for ball-bearings which is abroad in the land, we worked in quite a number, as shown in Fig. 5, in small scale, or more in detail in Fig. 6, and we firmly believe them to be a very valuable acquisition for this kind of work.

The balls *A* take all the thrust, and *B* and *C* the side load. They are inserted by unscrewing, for the moment, the plugs *D*, which were, of course, in place when the cylinder and the ball channels were bored out. The hole *E* affords drainage. It will be noted that the boring work is of a simple kind, cheaply done.

The balls themselves are inexpensive (these balls, 1 in. in diameter, cost about $2 50 per dozen). As will be seen from the drawing these bearings may stand out in the weather and run small chance of damage from rust or ice; moreover, they start easily in a sudden emergency, although oiling has been long neglected, and what is noteworthy, considering their many advantages, these ball-bearings cost only a very little more for shop work than the simplest ordinary form of babbitted journal.

Trouble from lack of long-wearing qualities does not arise in this class of mechanism; it moves so slowly and so comparatively seldom, or is in motion for such short periods.

Broken pinions and rack-teeth are so common on heavy gate hoists that we may be pardoned for presenting such simple machine details as shown in Figs. 7 and 8, which exhibit the forms and dimensions of those designed for this work.

This involute rack-tooth, with its great thickness at the root and the pinion shrouded at both ends, gives a strength ample for any computed stress due to the use of the gate, and a fair margin for such abuse as is sure to come once in a while when things are ice-bound, or a piece of water-logged driftwood gets under the gate. As has been said, $P +$ "Pat." must then be the value for use in our formula for stress instead of P alone, as given by the books.

Fig. 7 thus registers the writer's estimate or guess of the fair allowance to be made for "Pat."

The holes *D* are to allow water from rain or melting snow to escape, and were put in to escape a difficulty in which the writer once got caught in an earlier design where ice was formed in the pocket between double-shrouded pinion teeth, preventing working the gate until it was chipped out.

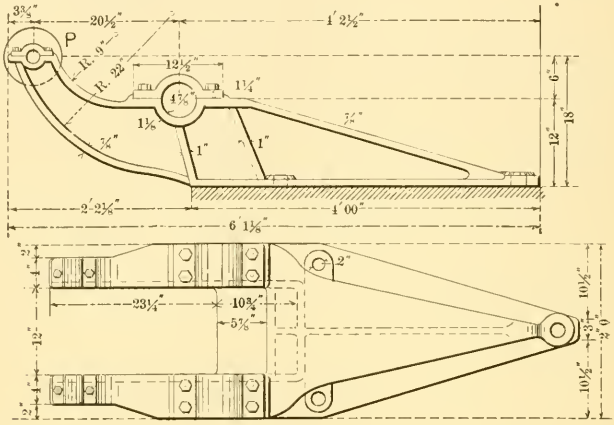


Fig. 9.

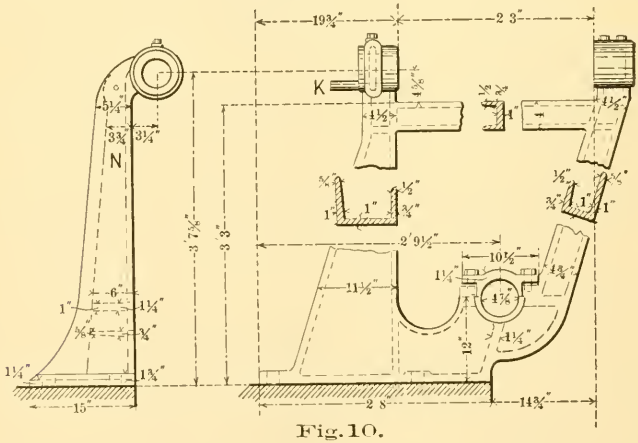


Fig. 10.

Figs. 8, 9 and 10 are other details, and illustrate the precautions taken to hold all bearings rigidly in line. The writer has ventured to trace Figs. 9 and 10 from a later design for another site, in which

certain slight changes were made in the patterns to improve the appearance and stiffness of the castings.

The front tie-bolts, 1½ ins. in diameter and 12 ft. long, holding down the pillow block of Fig. 9, were designed to be carried down to the great depth shown in Fig. 2, in order to suspend a sufficient weight of masonry therefrom, to hold the pillow block from lifting when the whole power of the gearing should be exercised in forcing down the gate against some possible obstruction.

The corner of the rack-tooth was rounded off, as shown in the longitudinal section of Fig. 7, in order to strengthen it by bringing any uneven strain back further from the end of the tooth.

It may be remarked, furthermore, that the power and strength of all the gearing was computed on the basis of forcing down a wide, open gate against a pond swollen by a summer flood, with an empty canal (due to some unexpected breach of the canal embankments), and that the necessary strength was computed on the hypothesis that the friction trucks on the main gates were not working, and that the roller bearings were inoperative, and the paddle-gates not opened.

In other words, the safety of the works was assured without these friction-saving devices, which were regarded as auxiliaries for saving labor.

The "paddle-gates" (Fig. 1, *A* and *B*) are for use when filling the canal after it has been emptied, and through them water is let in to balance the pressure on the main gates, much as a by-pass is used on very large water-pipe gates. They were placed at the top of the sluiceway under light head, that they might be easy to open and shut, and with the further object of avoiding the tendency to scour upon the canal bottom just below the sluices if filling the empty canal with water admitted under high velocity through a smaller opening near the bottom. With these paddle-gates, the first water falls vertically on the masonry sluice floor, and quickly has the energy for scouring taken out of it, before it reaches the wooden apron or sandy bottom a short distance down stream from the sluices.

Only three of the main gates are yet provided with these paddle-gates. These are each 5 x 2 ft. in the clear, and are of a total capacity sufficient to fill the empty canal in from about half an hour to an hour, according to level of water, and according to the leakage at the turbine gates. Of course the filling can be accomplished as rapidly as desired

by lifting one of the main gates, after the bottom of the canal has, by means of the paddle-gates, been covered 3 or 4 ft. deep to lessen the scour.

The hoisting rigging for the paddle-gates *C* (Fig. 1) is somewhat novel, and is carried upon the main gate-starts as shown in outline in Fig. 1. It is very simple, consisting of the notched wheel *E*, which is turned by a hand-spike or wooden lever 4 or 5 ft. long; on each end of the same shaft a 12-tooth pinion is carried which engages with a cast-iron rack of 1½-in. pitch and 3-in. face.

The starts *D* for these paddle-gates are of 2½ x 2½ x ¼-in. angle iron, and the angle of each lies compactly against the corner of the main timber gate-starts of the main gate, in order to lessen the possibility of its being knocked out of shape by an ice jam or by floating drift-wood. It will be noted that the whole of the main gate, including the trucks, can be run up easily for repairs above ordinary level of water in the pond.

These main gates are of Georgia pine 9 ins. thick throughout the lower half, and 7 ins. over the upper half.

The several planks are tied together by two large and tightly set bolts (*FF*, Fig. 1), 1½ ins. diameter, extending from top to bottom; also, by the two 8 x 10 gate-starts of Georgia pine, which furthermore serve as girders for stiffening the gate against the pressure of the trucks. The 6 x 6 x 1-in. angle irons at each end which serve as slide plates also stiffen and strengthen the gate.

A facing of 1-in. iron plates, 6 ins. wide, goes all around the edge of the wooden gate, to form a good wearing surface, and to make a securely tight joint with the iron plates facing the sluiceway masonry. For a head-gate joint, wood on iron, or wood on stone, might be the dictum of the old millwrights, but the writer believes that for durable working faces in sliding contact, iron on iron is far the best. Furthermore, it is the writer's belief that a water-tight gate can be secured more certainly where the lower edge shears past the edge of the sill than when it merely presses down upon the top of the sill.

The shearing force available from the weight of the gate and the power of the rigging is easily 25 tons.

In order that the middle portion of the edge of the gate might not lock in and become blocked against the corner of the sill, from being sprung inward a little by the pressure of the water, we made the top

corner of the massive cast-iron sill, already described, not horizontal, but slightly V-shaped, as shown in Fig. 1.

The computed weight of one gate, with its attachments, is about 5 tons in air, and, when near the bottom, the buoyancy of the water upon it will be about 2½ tons. The providing of two 2½-ton counterpoises for each gate was considered, and the works so designed that they can be added if they should ever be deemed advisable. The eye-nut *G* on the top of each main 1½-in. dowell bolt which extends from bottom to top of the gate furnishes a convenient means of lifting the gate by chain-falls in case of any accident or during repairs, and was also designed as a place to attach a counterpoise chain, which should run over elevated pulleys and lead to a counterpoise suspended above ordinary high water.

The writer considered, however, that a counterpoise was not worth its extra cost, and that the loss in lifting would be offset by the ability to let the gates run down rapidly under their own weight controlled by the simple friction brake, composed of an elastic oak lever about 1 in. thick by 3 ins. wide by 4 ft. long, resting on the fulcrum *K* (Fig. 10), and pressing against the worm shaft at *L* (Fig. 5), the outer end being held in the hand. From examining the finished structure (for, as already intimated, the writer did not personally supervise the construction, having undertaken the design with that understanding by reason of other engagements) this little detail of providing for a friction brake happened to get overlooked by the millwright.

This simple kind of a friction brake has been in satisfactory use at the north canal head-gates, at Lawrence, Mass., for many years, and it is found a great convenience to be able to let the gates run down much of the distance under their own weight; so much so that a counterpoise would appear objectionable rather than advantageous.

The worm-shaft stands were so designed that, should it ever be desirable to work these gates (or others with gearing cast from the same patterns) by electric power, for regulating the height within the canal, this could be simply arranged by bolting a worm-gear rim to the rim of the notched wheel *M* (Fig. 5) and driving the worm which engaged with it by a small electric motor which would be bolted to the face of the stand, shown in Fig. 10, at *N*, and run at high speed under control from a switchboard in the electric power station at the foot of the canal.

In this particular case the contingency of ever wanting any electric power attachment is very remote, since the extra height of the canal banks avoids the necessity for such close regulation as at most other powers.

The reason for placing the roller *P* (Fig. 9) at a higher level than the pinion is to facilitate the slight swinging off of the main gate as its trucks mount the wedges of their track.

The ratios of the train of gearing are such that one revolution of the pinion raises the gate 30 ins. and this calls for 126 revolutions of the crank, or one revolution of the crank lifts the gate very nearly one-fourth of an inch.

From 30 to 50 revolutions per minute can readily be made on a crank of this sort, and at 40 revolutions per minute the gate would be raised 10 ins. per minute.

DISCUSSION.

Clemens Herschel, M. Am. Soc. C. E.—The hoisting apparatus described by Mr. Freeman shows many refinements of construction put upon their good behavior in practice for the first time. Some of them are, in my opinion, unquestionably good construction, and will probably wear well; others I do not think are sound and good. It is pleasanter to refer only to the first class; but the latter kind should be referred to also. I place among the former the adoption of the Chicago foundation construction for the foundation and covering of the gateway arches; the details of the worm and pinion mechanism, including ball-bearings, steel endless screws, and general disposition of this apparatus, though I doubt, at the same time, the superiority of it over a screw and nut mechanism for lowering and hoisting.

Having a mechanism that admits of the possibility of letting the gate run down free, or only controlled by a hand lever, I also have my doubts about. I prefer a mechanism that holds the gate in place wherever it may happen to stand. The V-shaped sill is a neat device for preventing the catching of the middle of the gate on top of the middle of the sill, but my preference would be to have no rebate sill, and, instead, to have the gate shut down flat on top of a prepared flat sill. The object of the rebate is stated to have been the readier attainment of a water-tight joint; but I think this construction will tend to make difficult a shutting down of the gate water-tight, or anywhere near water-tight, by the lodgment in the rebate angle of sand, stones,

and similar trash, which the increased current when closing the gate will not dislodge; while a flat sill and gate can always be made water-tight by throwing a half dozen shovelfuls of ashes, or shavings mixed with gravel, on the up-stream side of the gate, after it is shut down as low as it will go, or nearly water-tight.

The fastening of these head-gates to roller wheels is a radical departure from accepted mill practice, which does not promise well in my opinion. Several constructors have tried to reduce the great sliding friction of head-gates by devices of this sort hitherto, on works already in operation. Mr. C. J. Cheney, of Lowell, some 40 or 50 years the millwright employed under our Past President, Mr. James B. Francis, designed and patented an arrangement of this sort about 10 years ago. He loaded the gate and the pressure upon it on a four-wheeled truck, as it were, by lifting the gate from its contact with its bearings when shut, and so as to bear on the axles of the truck, by means of four eccentrics on these axles, operated by an endless screw from above water; and in closing the gate he reversed the process, and unloaded the gate from the truck, back on to its gate-bearings.

Mr. Stoney, of England, has designed several sluice-gates on navigation works, among others several on the Manchester Ship Canal, some of them of very large dimensions, in which the gates have constantly between them and their gate-bearings roller-carriages like those under the movable ends of bridges. Of course such an arrangement cannot make a water-tight gate, which does not matter on navigation canals and at the points of water waste where these gates have been used.

Still more important is the consideration that such gates are not used in the winter, when navigation is suspended, while the winter time is the period of the most difficult service in the case ef water-power plants. In England the winters are also excessively mild, judged by our standards, so that many a contrivance used on hydraulic works in England becomes worthless when transplanted to the New England or other northern States of the Union. Many a New England engineer has probably looked with envy on the kind of grass-hopper structures that do service all the year around in Southern California, Arizona, New Mexico, not to mention Southern Italy and Andalusia, and has wished that he too might for once be rid of being obliged to design and build what seems foolish in the summer, when the work was going on, and the uses of which would only appear in the succeeding winter when he very likely would be alone in the struggle with the operation of the works.

But winter must be reckoned with, in our climate, and among its products is ice—ice in cakes, ice as slush, ice as anchor ice, ice on the surface of the water, ice in the water, and hard ice forming on iron and stone surfaces below water. The condition that our hydraulic

structures must all fulfill is that they must be operative, without breakage, in the coldest weather and under all conditions of the formation of ice; and I think it will be found that only exceedingly simple, or crude and clumsy structures, if anyone choses to call them so, will live and survive under those conditions.

I am aware, for example, that various contrivances have been gotten up to make a Stoney gate water-tight, in spite of its being mounted on roller-carriages, by Stoney himself and by others, so that they could be used on works other than navigation sluices, for which they were originally designed. These devices take the form of corner-beads and the like, say, like the weather-strips against windows, that keep out the winter's blast. But I have not heard that they have done their office during a winter in a climate like that of our northern States. In my opinion they should be expected to fail in operation during the winter.

Mr. Freeman, you will observe, gets over the difficulty of such leakage by letting the gate when shut run off its roller wheels, and restoring to it its bearing on the gate-bearings. This makes it water-tight when shut, or nearly so. And Mr. Cheney did the same thing in another way.

Now the only justification for doing anything of the sort, for taking any thought of the amount of resistance caused by the sliding friction of the gate on its bearings, for running any risk in the operation of the gate while trying to lessen this resistance, as well as for spending money in such a cause, would be a lack of power to overcome this resistance, as is found when men have to be sent to shut down, or to open up, the gates; but as is not the case, whenever water or other power is on hand or can be transmitted to the gate-house.

Let me give a homely illustration. A common drag for stone, or a stone-boat, as it is often called, with a yoke of oxen hitched to it, is a common sight on public works or on the farm. A boulder is rolled upon it, and the yoke of cattle plod along. They strain at the yoke, step by step, with their heads held low, the foam running out of their mouths in long strings, until one would think they are going to choke or until they actually do get stalled. Now suppose another yoke of cattle to be hitched on. These four will walk right along with the same boulder, step by step, in an easy swinging walk; and if two more yoke of oxen were hitched on, the show would consist of a pebble on a chip on the end of an ox chain, with hardly enough weight on the stone-drag to keep the chain taut, and the drag from swinging sideways back and forth. It is the same with a head-gate sliding on its gate-bearings; if only enough power be applied, its motion, whether of iron sliding on iron, or iron sliding on stone, or iron wheels rolling on iron, will not give a moment's care or even thought to the parties in interest, and will not authorize or justify the expenditure of a dollar

or the running of the slightest risk in the operation of the gate for diminishing friction.

Such abundance of power is generally at hand in the case of water-power plants. It is not at hand, as a rule, in the case of navigation works, which explains why these gates, running on roller-carriages, had their origin as navigation sluices. This sort of works is, as a rule, placed at a distance from towns or villages, at some lonely spot, with only a gate-keeper, his wife and a family of small children to attend to them. And a gate that he alone, or his wife in case of necessity, can operate, becomes a much better appliance than one that requires 20 or 30 or 40 H. P. on the shaft that moves the gate-rods.

In the head-gate houses of most water-power plants, there is usually placed a turbine water-wheel to operate the gates. This must be very carefully set so as to be operative under all conditions of ice, which can generally be done with steam piping, to melt out the anchor ice as a last resort. I have known a steam engine to be kept in reserve, with clutch couplings to make the changes. Also a steam engine to be used alone, or in conjunction with a reserve steam engine. One of the sets of head-gates at Lowell uses hydraulic pressure from the fire protection reservoir. And in these days of electric long-distance power transmission, to locate 20 or 30 or 40 H. P. at any head-gate ought not to be a difficult matter.

Such power is used, as a rule, but seldom ; only at long intervals in the generality of cases. But care must be taken, by duplication of machinery, or otherwise, that the power does not fail when wanted.

I think, therefore, that a better form of head-gate machinery would have resulted from supplying more power at the head-gates in question and having the gates plain sliding gates. And I doubt the working of the appliances used to diminish sliding friction when the gate, guides and wheels, and all the under water iron-work, will be encased in the hard ice that forms on such surfaces in very cold weather. In that event, one of two things is liable to happen, in my opinion. The gate will get jammed, so that it cannot be moved, or else something will break, neither of which eventualities is to be desired.

Finally, if mechanical power could not, under the appropriation for the gate-house, be applied, the gate could always have been made to move so slowly that one man could easily operate it. I built a gate of that sort at Holyoke, 14 ft. wide in the clear and 6 or 7 ft. high, a very large gate. One man opened and shut it, with no back pressure on the down-stream side to aid him, with one hand, but he had plenty of time to reflect on the mutability of human events, or on any other philosophical subject while he lowered or raised it 1 ft. But it did its work. In the winter time, when it jammed in the guides, a liberal application of kerosene oil would sometimes have to be used to rot out the attached ice. Moving the gate up and down could be resorted to,

to keep it in operation in excessively cold weather. It was nothing but a platform of 12 x 14 ins. hard pine, doweled, through-bolted, iron-bound, and having a slow but powerful gearing attached, to keep it going. I think it was a better gate for the place than would have been one modeled after the pattern of those here discussed. I think it was a better kind of gate machinery and running gear to have set up at the Sewall's Falls head-gate house, though better than either would have been some sort of mechanical power, plenty of it, according to the speed at which it was desired to move the gates and simple sliding gates. I say better, because I think such an apparatus would have been less likely to refuse to do its duty, at the time of some extraordinary occasion, which may be expected to occur upon any day during the severely cold weather that tries our work as the winters come around.

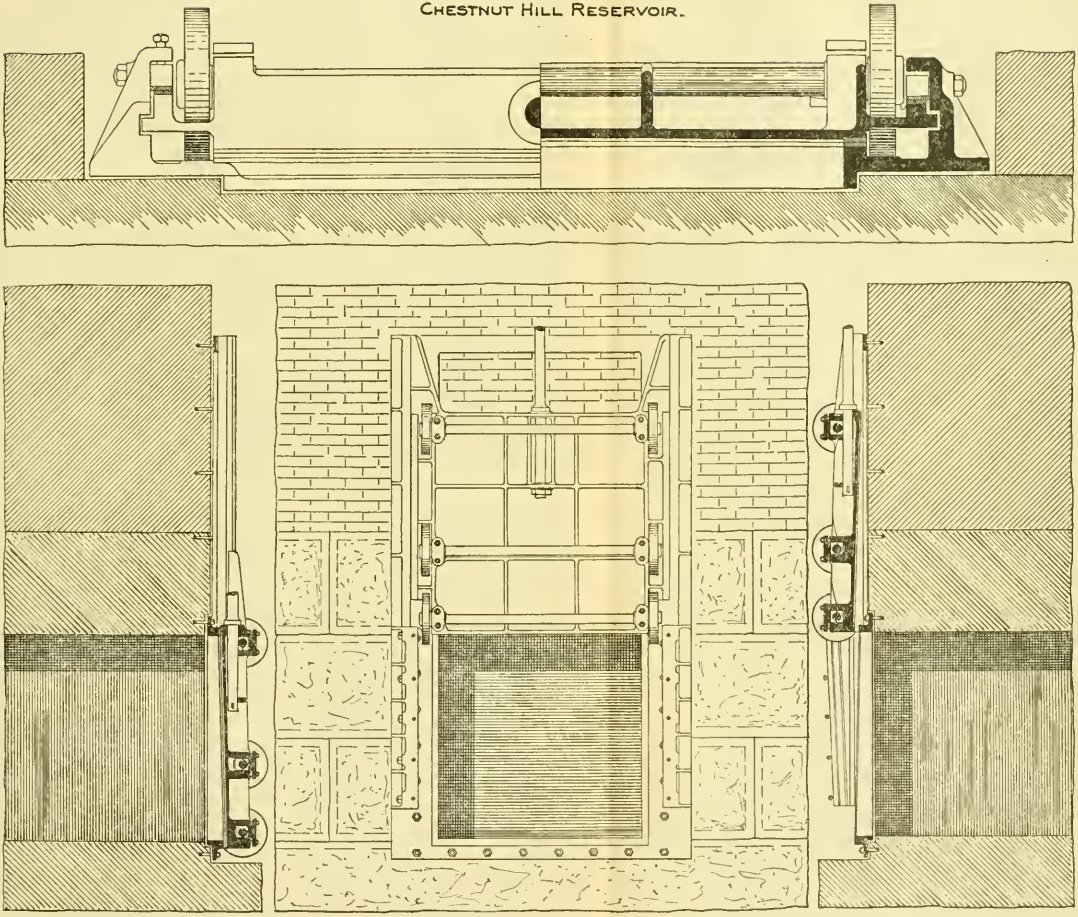
Desmond FitzGerald, M. Am. Soc. C. E.—This paper of Mr. Freeman's has interested me very much, principally because nearly 20 years ago I had occasion to design two gates for the city of Boston running on wheels. They are now in use at Chestnut Hill Reservoir. Although much smaller than those under discussion, being only 4 x 4 ft. opening, yet it is interesting to see how a problem is worked out on similar lines, but entirely independently, by two different people. Plate XLIII shows the Boston gates to which I have alluded. The stems are connected at the level of the floor of the gate-house with pistons in cylinders, which are filled with a mixture of glycerine and water. The gates run down of their own weight by turning a couple of valves, thus allowing the fluid to run from the under side of the piston to the upper side. The gates are raised by a hydraulic press, worked by man-power, and the gates can be raised quite easily with one hand.

It will be noticed in the design that the wheels are mounted on axles which run entirely across the face of the valve. The frames and valves are of cast iron, the latter heavily ribbed, to sustain the pressure of 25 ft. of water, under which they work. The sides are wedging in form, and just as the gate rolls to the bottom and is on the point of closing, the wedging action comes into play, the wheels rise from their track, and the brasses upon the valve and the valve seat come into contact. The gates are almost perfectly tight, and they have been working without any repair whatever for 20 years, and I have no doubt they are good for a much longer time than that in the future.

It seems difficult to understand how any one could secure a patent on a gate running on wheels when they have been made for so many years. I never saw one before mine were built, but the idea was given me by Mr. J. P. Davis, and I dare say that he received the idea from others. In this design Mr. Freeman has provided a very cheap construction combined with strength, particularly as far as the masonry is

48 inch Gate at Effluent Gate House.

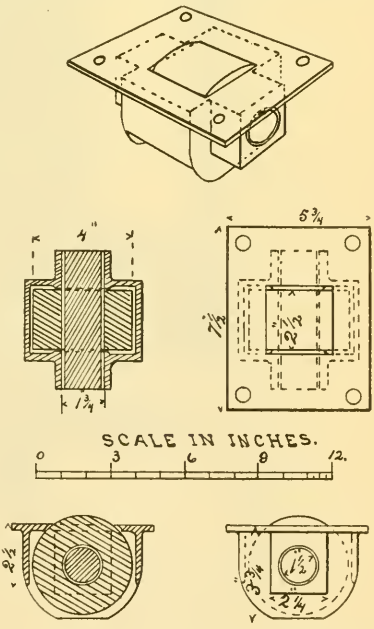
CHESTNUT HILL RESERVOIR.

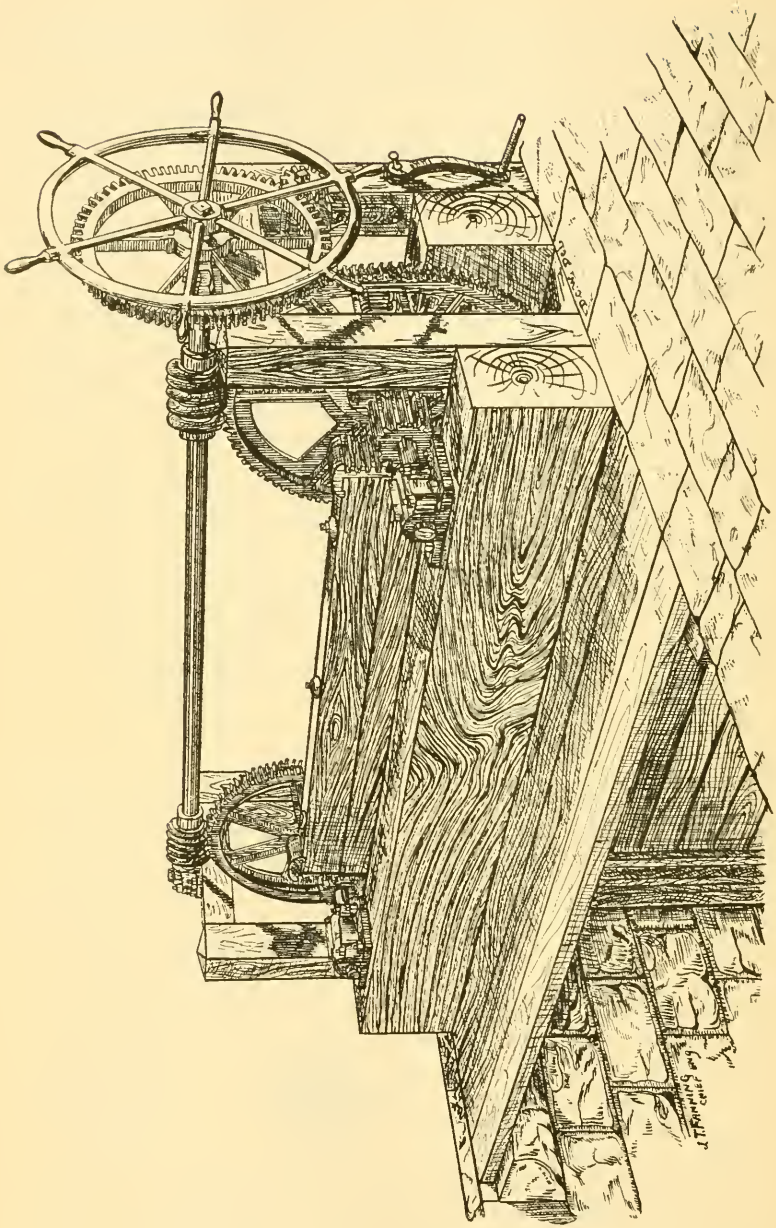


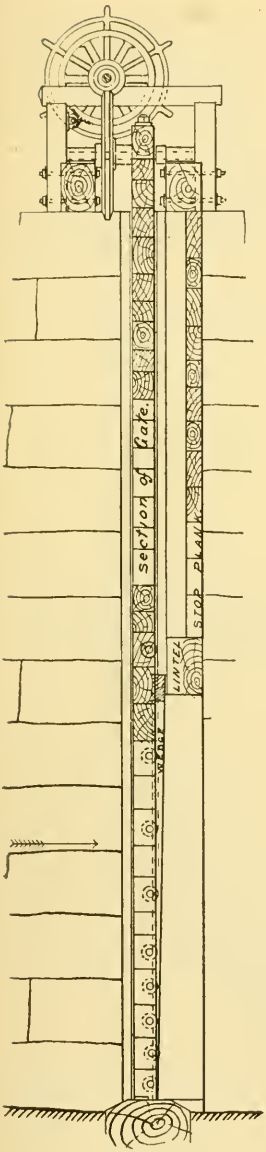
concerned, avoiding expensive cut stone. I am not quite sure in regard to the provision of power for working the gate. We have always found the friction of gearing very much larger than any calculations would give, but the practical working of the gate ought to show any weakness in this direction. Plate XLIII shows the details of the Boston gates so completely that I will not enter into a further description of them.

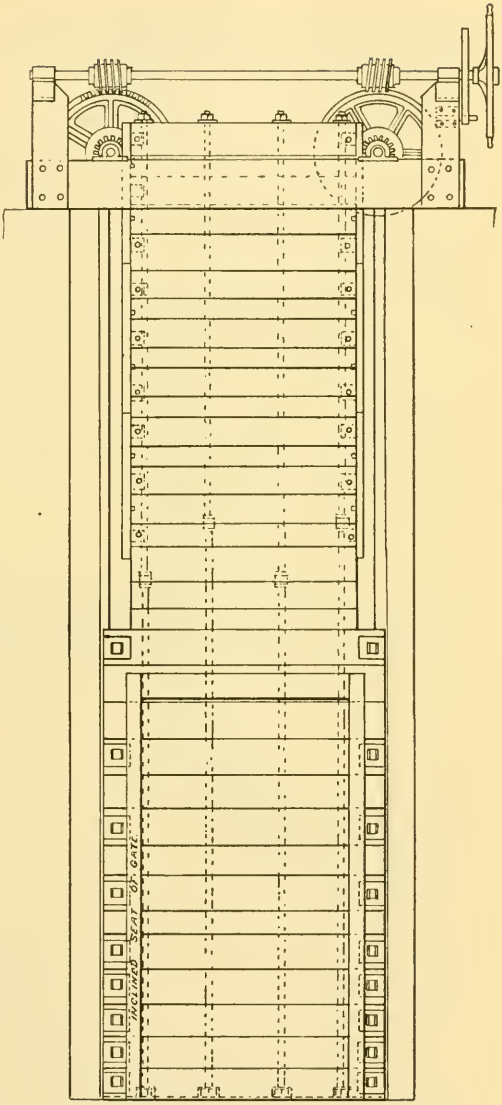
J. T. Fanning, M. Am. Soc. C. E.—When rebuilding a part of the dam at St. Anthony Falls, in Minneapolis, eight years ago, we found it advisable to put in waste gates in two locations. At one point there was a pair of gates; at the other, a single gate. Each of these gates is 6 ft. in width and 10 ft. in height, and the gate-sills are 16 ft. below the crest of the dam. Each of these gates has upwards of 20 tons water pressure upon the up-stream side, and no counterbalancing water pressure on the down-stream side. The sliding friction of these gates would be very great without rollers, and friction rollers were consequently planned for them.

On comparing Mr. Freeman's friction rollers with these, I observe that he used four rollers to each gate, one on each angle, and that his rollers are about 18 ins. in diameter and have axles 5 ins. in diameter. A larger number of friction rollers of smaller diameter were placed in the Minneapolis gates, nine rollers on each side, and so spaced as to distribute the pressure equally upon the sheaves. These sheave rollers are 4 ins. in diameter, and their axles, bushed with bronze, are 1¾ ins. in diameter. The form of each sheave is much like that of the window weight pulleys in a window jamb. They are placed on the bearing face of the gate. A plate of iron is fastened on the face of each gate jamb, for these friction rollers to move upon. These bearing plates are vertical and the rollers project ½ in. over the face of the gate. On the bearing face of the gate there is an inclined seat, tapering 1½ ins. in 10 ft. height of the gate-opening. Inclined seats are also placed within the gate jambs. As the gate is closed, it does not come in contact with its seat until just at the instant of complete closing. This

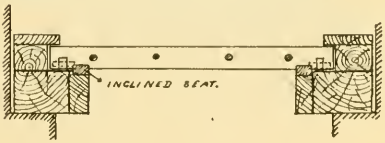








SCALE. FEET AND INCHES.



inclined seat gives a tight gate and permits the gate to be free from sliding friction upon its seat the instant after lift begins, after which it rolls up easily upon the sheaves. These gates are readily started and quickly opened by one man.

The cost of these sheaves is $1 50 each. On each edge of each gate there is a rack in which meshes the hoisting pinions. The pinions are operated by double worm-gear hoisting machinery.

These gates operated so easily and satisfactorily on first construction that I have since used similar gates on other water-powers in various parts of the country, but in the case of sets of head-gates, I have usually placed the rollers on one gate only, opening this gate first, to equalize the pressure on the two sides of the remaining gates.

Mr. FitzGerald, M. Am. Soc. C. E.—Is the bearing taken off the wheels ?

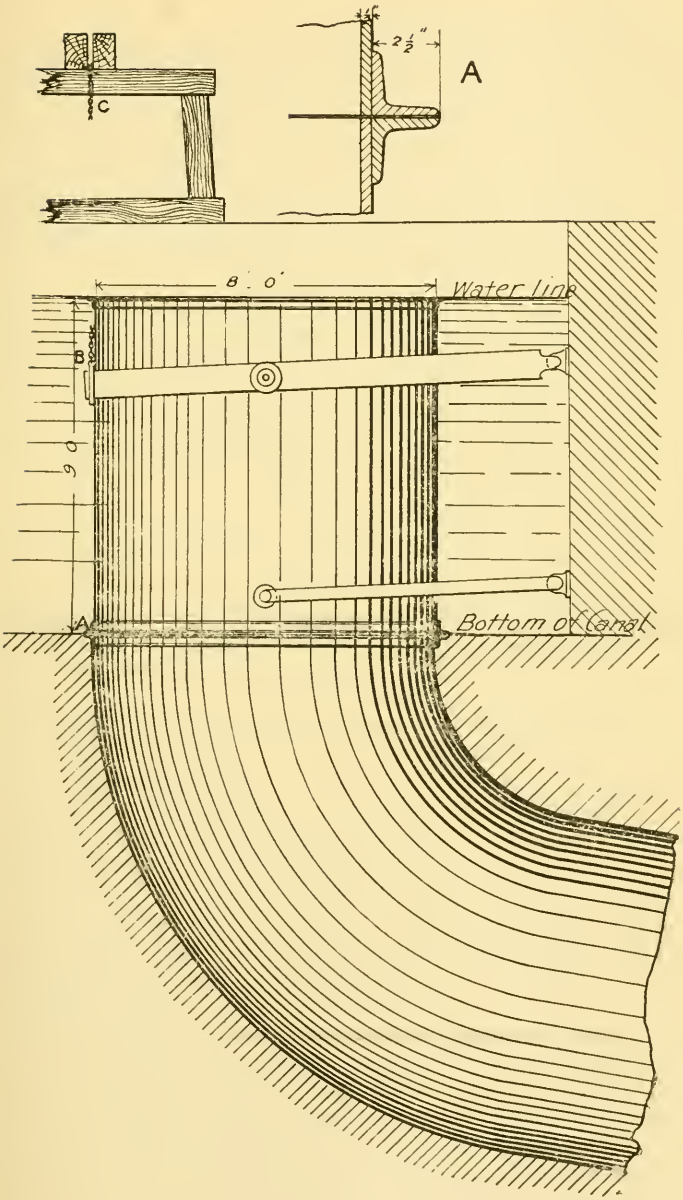
Mr. Fanning.—The wedge seats on the gate and jamb are in contact while the gate is fully closed, and at that time only relieve in part the pressure upon the rollers.

K. E. Hilgard, M. Am. Soc. C. E.—Have you had trouble with ice ?

Mr. Fanning.—We have to open various gates at different times during the winter, but rarely have had to open these waste gates while the river is frozen. In case we did have to open them, the ice could be removed from the jambs readily in a few minutes by the aid of a portable boiler kept for the purpose and a jet of steam, directed by a hose, upon the jamb.

William E. Worthen, Past President Am. Soc. C. E.—I have tried the principle of the bath pipe plug from time to time under different circumstances. I have seen gates that have been put in on that principle, and I have found them in the German works, so that I claim nothing for that idea, only the idea that I saw in the bath pipe plug. I put a gate in in 1888. It is a large bath, standard waste. It is connected with a pipe that extends down into the river, and the flow between the river and the canal is usually under about 35 ft. head. It discharges about two-thirds of the flow of the whole canal and has been in operation since 1888; so far the plan for hoisting it is nothing but a differential pulley block.

The pipe plug is 8 ft. diameter and 9 ft. high, the joint between plug and pipe extending to the river is made by angle irons, the movement of the plug vertically is controlled by radius bars working in centers on the back wall; each level of radius bars are framed strongly together with angle irons. The plug is raised by a chain hitched at *B* (see drawing, page 303) in connection with a differential pulley block suspended from *C*, and is dropped in the same way on to its horizontal seat.


C
2 1/2"
A
8' 0"
Water line
B
9 0
A
Bottom of Canal

Mr. Herschel.—Is that used in winter?

Mr. Worthen.—All the time.

Mr. Herschel.—Suppose the bottom gets covered with anchor ice?

Mr. Worthen.—They have made a house over it, and are using it all the time for the last eight years, but not daily, I think.

Mr. Herschel.—There is such a thing as anchor ice, and it would adhere to the seat of such a gate; how can such a gate be used when anchor ice is all over it?

Mr. Worthen.—A steam pipe would take care of that easy enough. I have never had any information from it except that the thing works; and when a thing works, that is what you want.

Mr. Herschel.—I question whether it has been working in the winter with anchor ice running in the stream.

Mr. Worthen.—It will work in the summer time, of course, and we could clean off the anchor ice if it is there. A steam pipe will blow the ice off. I don't think there is any trouble.

A Member.—Mr. Worthen, I think that bath plug of yours has been patented a good many times.

Mr. Worthen.—I have no doubt of it.

A Member.—How much did it cost?

Mr. Worthen.—I made it of that size because we had a piece of pipe about that diameter and pretty long.

A Member.—It did not cost anything then?

Mr. Worthen.—They did not complain about the cost; they used up all the old iron as well as they could. I don't know what the old pipe was intended for, but it came in very well.

T. C. Keefer, Past President Am. Soc. C. E.—In connection with this subject I should state that over 50 years ago, when they first proposed to make the Welland Canal locks of stone instead of wood, Colonel Macaulay, Royal Engineer, was Chief Engineer, and I was a young man under him. His plan, instead of filling through the gates, as the old canal did, was the old English lock, with breast wall and land tunnels in the side walls, which were square holes, both horizontal and vertical in the wall, forming a culvert along the whole length on each side, and these holes were closed by a bath plug such as Mr. Worthen speaks of. It was a square, solid plug of oak, that could be carried up in layers until the height gave the necessary weight. The bottom of the bath plug was an inverted truncated pyramid, and the seat corresponded. It was square and sloping. This was not an original plan of the Royal Engineer, but that of the small locks in England, and originated with the early English engineers.

J. P. Frizell, M. Am. Soc. E.—It appears to me that there is no subject in engineering to which so much ingenuity has been devoted as that of gates for controlling the passage of water.

I believe I understand the gate which Mr. Worthen has just de-

scribed. It consists of a cylinder standing over a circular opening. The latter is at the level of low water, the top of the cylinder is at the level of ordinary high water. The pressure of the water occasions no friction and offers no resistance to the raising of the gate. When the water rises above the top of the cylinder it operates as a waste gate with great efficiency, as it discharges under the full head due to the difference of level, provided that does not exceed the head due to the atmospheric pressure. This is an exceedingly simple form of gate, and susceptible of wider application than it has received. Gates upon this principle were used upon the old water-works of Paris nearly 100 years ago. I see no reason why such a gate could not be applied to an ordinary service reservoir, serving, at once, as a waste gate and an overflow. Usually, in studying any particular application of this gate, it will be found inconsistent with other conditions of the structure.

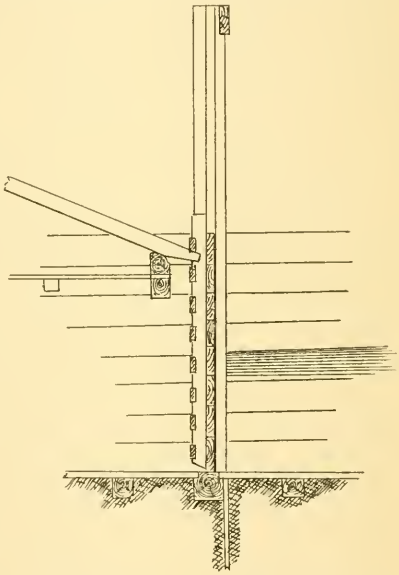
It is in very rare cases that gates running on wheels are to be recommended. It is usually better to apply the power necessary to move the gates, than to complicate their construction by arrangements for diminishing friction. In the head-gates of a canal, simplicity is more important than economy of working. Every additional part in such gates is an additional chance of derangement and possible delay. If the conditions imperatively called for devices of this sort, rollers, such as are contemplated at the power-house now under construction at Niagara Falls, would, to my mind, offer a more promising solution of the problem than large wheels. Again, if I adopted wheels, I should see no reason for departing from arrangements now in use at Lowell, Mass., which are said to have worked well. Mr. C. J. Cheney, of that place, is the inventor of a wheeled gate, which has been applied there in several cases. The peculiarity of this gate is that the wheel runs upon at rack or bar, which is cam-shaped in cross-section. When the gate is at rest, the wheels do not bear upon this track bar. The gate is held against its closing surfaces or seat by the pressure of the water. When the gate is to be raised, the cam-bar is turned through a quarter or half a revolution, and comes into bearing with the wheel, lifting the gate off its seat. The gate then runs freely on its track, which sustains the pressure of the water. When the gate is closed, the cam-shaped track bars are revolved out of contact with the wheels, and the gate rests firmly against its seat.

The hydraulic lift is an admirable arrangement for handling heavy gates. It is simple, free from complication and liability to derangement, not inordinately expensive, and where there is a domestic water supply, the power is always at hand. A force pump, to be operated by hand, is a sufficient safeguard in case of the failure of the mains. The cost of operation is trifling. For the head-gates of a water-power canal, which usually are not closed more than once a week, it is permissible to allow the gate to slide upon its seat or closing surface, but

for the wicket gates of large locks, which may be opened and closed many times a day, this is not desirable. Especially is this true of a wooden gate, or one with a closing surface of brass. To meet this condition, the simplest way is to make the sliding surface vertical, and the closing surface inclined. Then the pressure upon the gate does not have to be borne while moving by the closing surface, and the latter does not wear.

As to ice, it does not appear to me that there need be any difficulty in that, because you can always have your gates housed. Anchor ice only forms when you have open water above your bulkhead. So soon as the open water is closed by ice, you will have no further trouble from anchor ice.

The simplest and most convenient form of gate for depths of water not exceeding 5 ft. is made by lumbermen, and used for log and lumber sluices (see accompanying sketch). The gate consists of two uprights, sustaining the planking which forms the face of the gate. On the rear of the same uprights are bolted stout cross-pieces with intervals of some 6 ins. between them. The only lifting gear required is a couple of stout levers. The workman inserts the end of the lever under one of the cross-pieces, and weighs down on it across a block. The gate is lifted 3 or 4 ft., if necessary, above the surface of the water, and there fastened by a chock placed under one of the cross-pieces. To drop the gate it is only necessary to knock out this chock. The gate passes from the surface to the sill in a fraction of a second, so that the water has no time to drop away on the down-stream side, and so bring a pressure to bear on the gate while descending.



Mr. Herschel.—From the way the very eminent engineers who have spoken have received the remarks that have been made, I am inclined to think that there is a form of ice which has not been in their minds, and it is a very important form of ice to contend with. I say nothing about anchor ice, and do not wish at this time to take part in a discussion of that subject. You have all seen in a very

severe winter the handle of a door-latch covered with ice; it comes from the air, I suppose. The moisture is taken out of the air and is frozen. A similar but harder kind of ice than that forms below water. Take a corner filled by machinery, and in the corner there is still water. It is very cold weather, and by conduction away of heat from the metal surfaces the ice is formed. That is what I propose to speak of now. There are times when every little corner of a gate rigging will freeze up, or get coated with hard ice, and as far as one can see below the water, certainly some distance below the surface of the water, it is all one mass of solid ice. The gate will be frozen fast above the water, and above the surface of the water the ice shows in the shape that I have referred to just now; it looks like hoar frost all over the metal surfaces. The ice below water is very hard; it fastens everything together. I suppose it depends for its formation on little quiet places in the machinery. People that work with such machinery year in and year out have a way of looking at this matter entirely different from what we would be apt to get from looking at a drawing.

The gentleman who preceded me says you can house your gate; so you can, and you can also heat the house, and it is done as a general thing in New England; but that will not prevent the formation of ice below the surface of the water, nor even below the floor level.

Mr. Worthen.—I have had a little experience with ice. Ice forms in acicular crystals, which shoot across the surface of the water, and, if the water is still, the crystals come together to form a solid sheet; but if there is a ripple on the water, the crystals are broken up, mix with the water in the form of slush and attach readily to rock, iron or other material with which they are brought into contact. I have noticed a like breaking up of the crystals of saltpetre in the process of making gunpowder.

For many years I lived within, say, a quarter of a mile of the lower falls at Lowell, and I could always tell when the anchor ice was forming. As the anchor ice formed, the noise of running water was stopped, and I observed the condition of the air at that time, sharp cold, with a light breeze. If the mill pond froze over and kept frozen, there was no trouble with anchor ice.

Mr. FitzGerald.—About 18 years ago I lost a Christmas party from anchor ice, and, naturally, I have never forgotten that night spent in fighting this enemy of water supplies. Soon afterwards I began to study the question, and found it as Mr. Worthen says. The water in a reservoir begins to cool down in the winter, and if there are heavy winds it may not freeze over until after the whole body of water is cooled to the freezing point. This generally occurs at Christmas time with us. I now keep the run of the temperatures of the water, and if I find that the whole mass of water is in this condition and the surface

not frozen I keep men in the gate-houses to watch for anchor ice. It will form in a very short time after the conditions that I have described have been reached.

The anchor ice that I have observed is in the form of thin scales, about the size of a half dollar and needles. It comes in with the current, apparently from all parts of the body of water, and it has a way of collecting in punky masses, which soon fill up all openings. In my principal gate-house I have a steam pipe laid reaching into the water in front of the screens, so that I can quickly blow steam down into the masses of anchor ice and break them up.

J. F. O'Rourke, M. Am. Soc. C. E.—I want to say a little about anchor ice. I think the definition of anchor ice is one that is, perhaps, not understood in the same way by everybody. Our idea of anchor ice was that it, as Mr. Worthen describes, was ice that formed as slush, and finally became solid by running together. The fact that ice will form under ice from clear water to a considerable depth is one that came under my observation when we were building the Wisconsin River Bridge. It was about 20° below zero, and we put in pile foundations for piers. Those foundations were driven, and, some time afterwards when convenient, were cut off. There was 2 ft. of ice over the river at the time, and when the piles were sawed off, perhaps 15 ft. below the surface, the butts were covered with solid ice all the way from top to bottom. The only explanation we could give was that the water was in the condition Mr. Herschel describes; it was just at that point when it would give up the latent heat. Something that would remove enough of the latent heat to convert it into ice was all that was necessary. We accounted for the formation of this ice by the fact that these piles were exceedingly cold when driven, and that the frost penetrated down through the piles. I think the same thing is true of these gates. The top of the gate is out of water; it becomes much colder than the water can become without freezing, and contact with it freezes the latter far down below the surrounding ice that is covering the surface of the water.

Mr. Herschel.—The gentleman has described what I have attempted to describe to the meeting. I know, I think, a little about anchor ice, but I have not wished to discuss it to-day. The kind of ice that I think is the worst is what I wished to describe.

Mr. Keefer.—I would like to ask if the piles were standing in open water, and slush ice above and below?

Mr. O'Rourke.—It was very rapid water; the pier was at the side of an island in the channel.

Mr. Keefer.—Then there was open water above?

Mr. O'Rourke.—No, sir.

Mr. Keefer.—Was there water uncovered by ice anywhere above where the piles stood?

Mr. O'Rourke.—No, sir; the water was not all over the piles.

Mr. Worthen.—How far up?

Mr. O'Rourke.—There was perhaps 3 ft. of ice all over the river.

Mr. Worthen.—How far up was it frozen over?

Mr. O'Rourke.—It was frozen over all the way up as far as you could see.

Mr. Keefer.—Then there was no open water above that point?

Mr. O'Rourke.—Only such as was caused by the progress of the work. There was no opportunity for slush ice to form.

Mr. Keefer.—My reason for asking the question is that we find anchor ice will run 10 or 12 miles, more or less, according to strength of current, under the surface ice. That is a common occurrence in the St. Lawrence; in fact, at the beginning of winter it passes through the whole length of the river before that is frozen over. At the ice bridge, which first forms below Montreal, the floating anchor ice is carried under the surface of the bridge ice and accumulates until it hangs down from the under side like a gigantic wasp's nest; 50 ft. down, in some cases, where the water is deep enough. I have found it to extend 90 ft. below the surface at the head of Lake St. Louis and foot of a long rapid.

With regard to the formation of anchor ice, I think it has been correctly stated by Mr. Worthen and others, but as to its starting on the bottom or growing on the bottom I believe the explanation to be this: We find that at the first the whole surface of the St. Lawrence River is covered with the slush ice, which are needles of crystallization broken up by wind and current and drawn together by mutual attraction into little bodies and masses, and sometimes you will see the surface of the St. Lawrence covered with slush ice. That passes down until the water gets cold enough to bridge the river over, and where a lake or the tide meets it a bridge is formed, and the descending anchor ice gets directly under, and it glides along on the other side until its velocity is sufficiently retarded by friction to permit it to stop, when it freezes to the under side of the ice and grows downwards. When the descending ice has been elbowed by the current into all the side channels, confining the main current into one central part that carries this ice so much farther down until arrested by the surface ice, when it grows downward, forming a suspended dam, and then the river begins to rise and backs up until the winter level is 10 or 15 ft. above the summer one, and the wharves of Montreal are covered.

As you all know, and as Mr. Francis demonstrated, the surface water in a strong current or rapid descends to the bottom and rises again all the time; this not only reduces, as I believe, the temperature of the water at the bottom to the freezing point, but decidedly below it, and what only prevents the water from freezing solid is its motion; if it rested, it would freeze at once. The result of that is that a cur-

rent of water colder than the freezing point passes over the stony bottom which causes a rapid radiation and reduces the temperature of the bottom (as would a cold wind the human body) to such a point that the ice needles in the water take hold of the bottom, or the bottom takes hold of them, and "anchored" ice grows rapidly. I have known it to cover the whole bottom of the St. Lawrence, which, in open water, it covered to a depth of 2 ft. before it stopped growing. I have gone out on the river and put a pole down and pried up some of it, and it would come up with a rush and then float down. I have gone out when the thermometer was 20° below zero and I have looked out over the surface of the river and it was as clear as the Niagara—no ice on it; there had been several days of below-zero weather, and then suddenly the thermometer rose to 40°, the ice let go from the bottom and the whole surface would be dotted with white caps. They would burst up from the bottom, drain out at the top and settle down with 90% of depth below surface and sail away down. I have no doubt that our ice floods in Montreal are entirely due to anchor ice. Bridge ice, surface ice of any kind, would never sink and could not cause a dam, because these floods take place when the flow of the river is a minimum, there being no flow at all from the surface, and none but the very large streams bringing in much water. I believe, therefore, that the whole of our enormous winter floods at Montreal is due entirely to anchor ice formed in this way. It should be explained that the ice bridge is formed of floating ice, tilted by the current and standing on edge and exceedingly rough on the under side, just suited to catch and hold the anchor or slush ice which only goes under.

Arthur De Witt Foote, M. Am. Soc. C. E. (by letter).—The abstract of the very interesting description of these large head-gates built by Mr. Freeman reached me sometime after it was issued, but was of particular interest, as I was just finishing a design for a series of gates of almost precisely the same size and intended to bear about the same pressure.

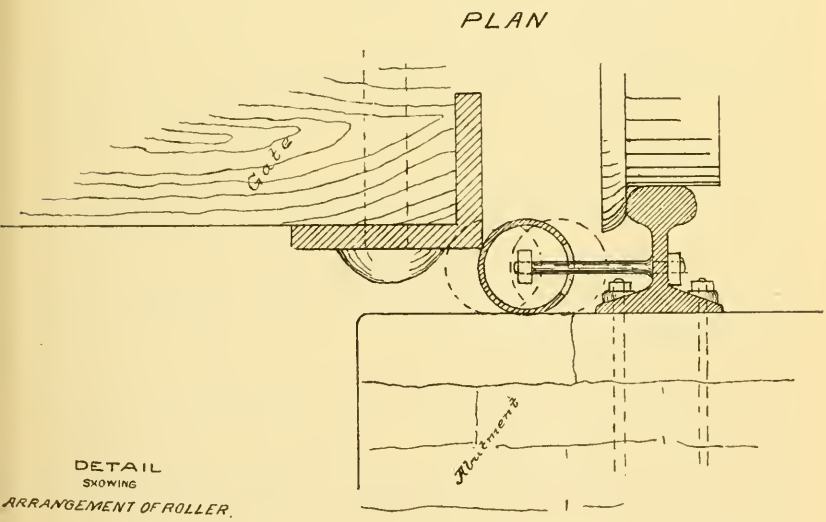
Some years ago I designed a large gate for use under a heavy pressure to run on wheels on a track like an inverted flat car, but in that case the gate was of steel and did not touch the abutments. In other words, the gate was held by the wheels so as to allow a ½-in. clearance and consequent leakage between its face and the structure. The leakage was no objection, except as it might draw drift into the crack and wedge the gate. Wishing to avoid this crack in my present work I was led to contrive something that would close it and still keep the gate from bearing on the abutments and consequently "sticking."

Here is where Mr. Freeman's method of having recesses for the wheels to drop into and thus bring the gate to a bearing appears to me to have serious objections. The gate not only will "stick," but the first few inches that the wheels travel on their way upward is up-

hill in reference to their load or pressure as well as in reference to gravity.

I have therefore kept the track for the wheels straight, carrying the gate so as to give 2 ins. clearance from the abutments, and, in between the tracks and the inner vertical corners of the gate, 3-in. pipes or rollers are fixed in such a way that they can roll backward and forward 3 or 4 ins., yet touching the abutment. The upper ends of these pipes or rollers are tapered so that the corners of the gate in descending will not strike them, but will wedge or roll them to one side and pass down between. The pressure of the water will hold these rollers in place so as to fill the crack or clearance space between the gate and the structure. The accompanying detail drawing will show the position of the rollers and method of holding them so that they can roll each way.

A 3-in. pipe is used simply because it is a cheap form of roller.



It will be observed that with this method the only friction produced by the gate itself when being raised is that between its vertical corners and the rollers. The pressure forcing these rollers against the gate would equal, approximately, the water pressure on an area 3 ins. wide and as high as the gate, an insignificant amount compared with the pressure against a 10 x 12-ft. gate.

On the top of the gate something similar in principle might be used, but for my present work I shall simply fit a piece on to work as close to the face of the structure as possible and expect a trifling leakage.

In the matter of a gate hoist I have adopted two stems with the ordinary form of ratchets and connected geared winches, one turn of the handle raising the gate ½ in. I have arranged the cog wheels next the ratchets, however, so that each have two bearings, one on each side, close to the wheel, having found that where a bearing on one side only is used, the shaft is liable to spring under heavy strain sufficiently to break the cogs.

Of course, the idea embodied in the foregoing has not borne the test of experience, and it may seem ungracious to present it as an improvement on Mr. Freeman's design which is working, and working well I have no doubt; yet, as an idea it may be worth the recording, and if it prove a success Mr. Freeman will be the first to welcome it.

Robert A. Cummings, Assoc. M. Am. Soc. C. E. (by letter).—If the distinguished author of this paper deems it necessary to express his *motif* for communicating it to the Society, it would seem obligatory for a younger member to apologize. It is therefore with a considerate deference to the views of the author that the writer ventures on the floor of discussion.

The method here adopted for reducing the friction in raising canal head-gates has given rise to a vigorous oral discussion, during which it was pointed out that one man could do the work effectually by simpler means.

Realizing the enormous sliding friction of the contact surfaces of head-gates with a high river and empty canal, it is obvious that whatever power is applied in raising the gates, does not reduce their frictional resistance. The author, therefore, has used a rolling-friction method to reduce the frictional resistance, but with the multiplication of moving parts, bearings, etc., the writer would ask what is the estimated saving in friction?

The probability of dirt settling in the bearings and corroding them makes it an exceptional piece of construction, the future operation of which would be interesting. A comparison of the theoretical and actual power absorbed by the rolling friction of the gates would give some much-desired information on rolling friction under pressure.

The writer desires to record a method devised by him for reducing the sliding friction of head-gates, which it is thought may have a wide application in similar structures.

Returning to the author's method it is self-evident that the clearance of ¼ in. or ½ in. from sliding contact is the main advantage secured where the rollers carry the load. This clearance of contact surfaces the writer accomplishes with a plain ordinary gate by introducing between the surfaces a film of water under pressure. The gate slides on the water only and is raised in the usual manner or by a hy-

draulic ram. The escape of the water is of inappreciable consequence. The pressure may be readily obtained from a hydrostatic hand pump, an elevated tank, or as circumstances dictate.

The formation of anchor ice, which is so common in the winter, must be cared for by a portable steam boiler and warm water used as pressure water. The temperature of the metallic portions of head-gates has a natural tendency to be uniform in a more or less degree, which may account for the formation of anchor ice below water-line.

James Francis, M. Am. Soc. C. E. (by letter).—The discussion of Mr. Freeman's design of the hoisting device for the head-gates at Sewall's Falls gives me the opportunity to describe briefly a form of gate which has been in use at Lowell during the past 10 years.

The proprietors of the locks and canals on Merrimack River have, at the present time, six gates at five different places, which can be moved from their seats by various methods, and the loads, due to the pressure of water against them, together with the weight of the gates, can be transferred to bearings, resting upon four to six wheels for each gate, and, after this transfer has been made, the gates can be operated up or down, like a car on a railroad track, with the rails in a vertical position.

The first appliance of wheels to water-gates, in Lowell, was made about 10 years ago, at the speed-gate of a turbine, where the water was admitted to the buckets through a wood scroll. The gate was 3½ ft. long by 2-ft. rise.

The very old hoisting arrangement there, consisting of a small worm and gear, in connection with a rack and pinion, had become worn out, and a new device, invented and afterwards patented by Cleveland J. Cheney, the Superintendent of Labor, was substituted. It was a crude apparatus, but it served the purpose of operating the gate quickly and easily, after the load was transferred to the four wheels.

Most of the other gates are placed in the wasteway dams, which are situated at various parts of the canal system, and they are operated under heads of water varying from 8 to 15 ft., or more, above the sills. The later designs are vastly superior to the first one which was built 10 years ago. These gates, which have a pressure of water against them varying from 2 to 15 tons, and sometimes more, can be readily and quickly operated by one man.

The first operation to be performed is to transfer the load from the seat of the gate to the wheels, which in the latest designs can be done by turning one-fourth round a vertical cam rod placed near, and parallel with, the end of the gate by means of a lever, and then turn-

ing another similar cam rod at the other end of the gate, which produces the effect desired, viz., the transfer of the load from the seat of the gate to the four or six wheels, which now bear upon the cam rods. The cam rods are made of steel, and they are secured in metallic boxes or journals at the sills and again near the top, and are made long enough to reach to a point above the surface of the water, where the operator can work the lever to the best advantage.

After this operation is completed, the gate can be readily raised, with the expenditure of but little power compared to the power that would be required without the wheels, by turning a crank which is connected by gearing with the vertical start or post which is attached to the gate.

The gate can be lowered with equal facility, and, after it is shut, the cam rods are turned back, and the gate is relieved from the wheel-bearings and comes to a firm seat against the slides, which prevents any further leakage around the sides.

The important feature of this design is the transfer of the load to the wheels before the gate is started.

Another feature regarded as essential is the counterpoise, which serves to balance the gate and to equalize the power of raising and lowering.

The writer regrets that he has not been able to prepare drawings of the gate machinery described within the time left to him since his attention has been called to this matter.

John R. Freeman, M. Am. Soc. C. E. (by letter).—I had hoped to present this paper in person, and, if then joining orally in the discussion, could, perhaps, have made some points more clear.

I am pleased that the design received such full discussion, and there is no part for which I am more grateful than for the frank criticism by my friend Mr. Herschel.

I understand Mr. Herschel's criticism on roller-bearings is directed more particularly toward cases where water-power or other power is available for hoisting the gate, not cases where hand-power must be used from reasons of first cost.

The intimations as to what may be feared from ice prompts the reply that I was not without thoughts of this when making the design, and can yet see no grounds for fear.

Ten years of winter and summer work on and around one of the chief water-powers of New England did not permit me to forget that water is not always fluid, or to forget that zero weather and ice, freshets and driftwood, control the factor of safety in structures of this class; neither can I, after having supervised repairs upon two or three bad washouts, in different parts of New England, forget that an important canal guard-gate should be capable of closing quickly

against an empty canal, with but one pair of hands for a prime mover.

Replying further, in order, to the various comments and criticisms, I submit that:

First.—One superiority of the rack and pinion gate-hoist over the screw and nut gate-hoist, for low-cost work and exposed situations, is that it is much cheaper. The rack and pinion is almost wholly foundry work, worth finished, say, 3 cents per pound, with a little carpenter work on the uprights; the other (say a 5-in. wrought-iron screw 14 ft. long) is machinist's work of an expensive class.

The rack-gear is more easily freed from ice than the screw, and, with the massive timber gate-start behind it, can better withstand a log-jam or ice-thrust than the more slender screw.

Gates lifted by screws should be placed within chambers, with a masonry wall carried over the up-stream ends of the sluice-piers, to serve for a fender and to house them from extreme cold. This again adds to the expense.

Second.—Doubts concerning a mechanism which runs down free, controlled only by a hand brake, may be lessened in view of the successful use of precisely this means of lowering at the North Canal head-gates, at Lawrence, Mass., twice each day for about 46 years. The quickness and ease with which a gate can thus be lowered, for about two-thirds of its height, is a point in its favor, and led me to dispense with the counterpoise.

Third.—The collection of gravel or rubbish against the rebate of the sill is provided for by a triangular block, which does not show clearly in the engraving. This forms an incline at about 30° just up stream from the face of sill, with the top of the slope about 3 ins. below the bottom of gate, and it is my hope and expectation that should any gravel or similar obstruction not scour through, that, when pressed by the descending gate, it will be pushed up stream down this slope enough to let the gate lap over the sill enough for a water-tight joint. Moreover, it is probable that gravel, sand or water-logged rubbish, rolling along down stream, will not fill up entirely flush with the up-stream edge of a sill where there is so swift a current, but will scour out a few inches below its up-stream edge.

One trouble that I have noticed in closing other large sluice-gates tight has come from water-logged brushwood getting caught under the gate; therefore in this design, and in one large gate previously designed, I thought I would try making the lower edge of the gate and the edge of its sill into a pair of mighty shears.

So far, the gate built in this way has proved very satisfactory, and the first one, just referred to, though often opened and shut, and with its leakage always in plain view, is remarkably tight without any

necessity for the "dusting" of ashes, shavings and the like, prescribed by Mr. Herschel for gates with a flush sill; and, by the way, as I have on perhaps a dozen or twenty occasions, passed some long and weary midnight hours waiting to enter a flume or wheel-pit, watching men bring coal ashes, gravel, picker dustings and burlaps by the barrelful and dump them in front of a gate with a flush sill. I know that a flat-sill gate can not "always be made water-tight by half a dozen shovelfuls of ashes," etc.

Fourth.—Roller wheels on head-gates would in many cases be unnecessary. At the head of an ordinary turbine penstock, or at the back gate of a wheel-pit, they would generally be an unnecessary complication, for such gates are seldom closed. The pressure on opposite sides can commonly be balanced while closing or raising, or in an emergency. At the time of a breakdown there are many willing hands around to furnish abundant power.

For a waste-gate to prevent an important canal or reservoir from overflowing, for the guard-gates at the head of a canal with easily destructible embankments, for a large regulating gate which must often be opened and shut without counterbalancing pressure on its downstream side, for important controlling gates off in the woods at the end of a telephone wire, I still believe such devices as roller-bearings to be of great value in enabling one man to exert the power of three men, or conversely, to do the work in one-third of the time possible with slow gearing.

The first gate that I built with roller-wheels was put in service about three years ago. It is over an opening of 28 sq. ft. area, under 10-ft. head on its center, and with no back pressure. The rollers can be thrown into play or out at pleasure. The master mechanic of the factory in whose yard this gate stands has lately been making some experiments on that gate by hanging weights on the hand cranks, placed horizontally, and finds that 33 lbs. will move the gate when the wheels are in play, and that 140 lbs. are needed when the wheels are thrown off.

This simple expedient of the wheels, therefore, enables 22½% of the power to do the same work, or one man to do the work with the rollers with the same ease as four men without the rollers.

This earlier gate was described by me in connection with an ice weir in a paper before the American Society of Mechanical Engineers (June, 1894, Vol. XV of *Transactions*), and the points therein developed bear upon this question.

This earlier structure, with its roller-bearings, has passed through two winters, one of them exceptionally severe. The gate is at the center of a wasteway for running off ice, and not the slightest defect or difficulty with any part of it has developed.

It stands guard against the overflowing of a canal 2 miles long, with

an easily destructible embankment of pure sand, and it was thought desirable to have a waste-gate which a night-watchman could raise quickly. The roller-wheels enable one man to do the work of four, as already stated.

Fifth.—Power other than manual strength for hoisting head-gates is a good thing when you can afford it, but out of the many large American water-powers, only Holyoke, Lowell, Bellows' Falls and Manchester are the ones which I recollect as having seen possessing it. Lawrence, Lewiston, Rumford Falls, Palmer's Falls, Berlin Falls, Nashua, Spokane and probably some scores of others of above 2 000 H. P. are without power hoists.

For the great majority of these the head-gates are worked but seldom, and then under circumstances when it does not matter much whether one man or six is detailed for this short job.

To illustrate the conditions governing in many cases, here at Sewall's Falls to put a turbine with accessories and connections for working the gates would have added probably at least $3 000 to the cost, and perhaps more, and it would have stood idle months at a time.

To multiply the gearing so that one man could work it comfortably would make the time of hoisting or of shutting in an emergency intolerably slow. Now, what did these roller-wheels with their trunions and special railway add to the cost? The four for each gate cost, altogether, about $185. I think they are worth this.

Be it noted, so little do they add to or complicate or modify the structure, the hoisting rigging and the gate being complete without them, they could be taken off in a few hours, and without adding anything whatever in their place, there would be left an excellent example of a gate fully equipped for being pulled up by four men to a crank in the good old-fashioned way, for all the rigging above is made as strong as though the roller bearings did not exist.

Sixth.—I don't see how these roller trucks are likely to get injured by ice, for it will be noted they are extremely massive, but suppose the rollers and their tracks become encased in ice, how can their existence increase the chance of breakage? You then will have at the start merely four "sled runners" instead of four wheels, and a 20-ton pull available to start the load, and with an axe and a pry and an "arch-kettle" full of hot water, the chances are fair that the gate can be started at least as easily as in the days of yore.

A slow-speed arrangement of great power, such as Mr. Herschel recommended, is provided in the ratchet bar, forming a part of this outfit, and by the time the man has, under the powerful purchase of this device, pulled the gate up 2 or 3 ins., the ice lodged in the wheel trunions, or along the track, will probably crush and cease to be very much of an incumbrance.

For Mr. FitzGerald's contribution to this discussion, I must return special thanks, since the 20 years' successful use of his roller-wheel device strengthens my confidence in the success of the gate-rollers described in this paper. It is curious to see how closely the two independent designs run parallel in the manner of lifting the gate off its slides by wedge-like tracks. I had seen no such arrangement before.

Mr. Hiram F. Mills, C. E., at about the same time that these Sewall's Falls gates were built, was introducing a very similar device of his own design at the canal head-gates on the large water-power at Winslow, Me.

The device which Mr. Fanning has contributed to this discussion, with its remarkable low cost and its eight years' record of successful use, appears to have a special field of usefulness.

After learning also, of the ingenious device of Mr. Foote, in connection with large gates carried upon rollers, I can but feel much pleased to find that my use of roller bearings has brought me into such excellent company, and, when my opportunity comes to try again, I shall surely profit by this present discussion.

Again, if trying, I should consider the avoiding of the endless screw arrangement, and using a secondary gear or two to gain the same speed reduction and gain in force, with, if possible, less loss in friction than involved by the best of worm gearing.

In experimenting recently at Sewall's Falls, with this apparatus at the top (which has not been properly protected from the weather, or well oiled, and has, therefore, become quite rusty), I find that the sharp angle of advance of the worm screw causes it to bite against the cast surface of the worm wheel with rather too much friction. This action being more noticeable than in an earlier design where cut worm gears were used.

Mr. Wm. E. Worthen has brought forward another style of gate which certainly has much to commend it for certain situations in furnishing at once a waste-weir and a balanced gate. I have had some experience with these, but had supposed them indigenous to about the latitude and longitude of Southern New Hampshire, and that they were the invention of Daniel Hussey, years ago a noted millwright and cotton manufacturer. From one cause and another, the half dozen large gates of this type which I have happened to see have been displaced within 10 years past by gates of the vertical, flat, sliding type. It is but fair to say that none of these was planned with such stiff and rigid foundations as might have been used advantageously, and were less strong in their bearings and supports than would be designed by an engineer of Mr. Worthen's great experience.

The men who operated these old "tub-gates," as they were called,

were prone to concur in the view expressed by Mr. Herschel and wish them in Andalusia, Arizona or some other hot country, where ice never forms; still the type seems to possess marked advantages for a drain-gate and with only the drawback that, so far as my little experience with them goes, it is sometimes difficult to shut them tight. It certainly is a type which ought to survive and for quick, easy action, for perfect balancing of the water pressure, and for containing within itself an over-flow weir of very considerable crest length, it excels any type with which I am acquainted.

They appear better adapted for a gate to be kept shut than for a gate to be kept open, and where the friction loss in the water flowing through them must be kept small, they present the same disadvantages as a globe valve, the two sharp right-angle turns to the current. By reason of the space they occupy they are not well adapted to handle very large quantities of water, as, for instance, upward of 1 000 cu. ft. per second.

For canal guard-gates alongside a river, I should always distrust them by reason of the tortuous passage (like that through a globe valve), not permitting a drift log to pass.

On the question of anchor ice, it may not be amiss, since two of our members have called attention to the desirability of a special turbine for furnishing power to hoist the gates, to recall how anchor ice stopped the working of the gate-hoisting turbine at the Northern Canal in Lowell once many years ago. In the early morning just before starting time for the mills, the turbine speed-gate was raised, that the main sluice-gates might be opened. The turbine immediately plugged up with the interlacing needles of anchor ice and would not move. Thousands of operatives were waiting to begin their day's labor, and tradition says things were in a terrible state around that gate-house for two or three hours, but just as other means had been improvised, the sun got up so high over the adjacent walls and roofs that its rays fell in the water in front of the feeder to this turbine, when suddenly the turbine started up and jogged along as if nothing had ever been the matter.

To the very interesting remarks of our Past President, Mr. Keefer, I will add but one brief observation. Ten years ago I was making soundings in cold December weather at mid-channel in some rapids on the Merrimack River from a boat held by a hawser stretched between trees on the bank. The cold had not yet fully closed in the river above. On prodding the rocky bottom with my sounding rod, I found it almost everywhere covered, even in swift current, with irregular masses of interlaced needles of ice from 2 to 4 ins. in thickness. I pulled up many bunches with my boat-hook and in some more shallow places could see their spongelike masses plainly *in situ*.

The special peculiarity which I noticed was that the bunch was perhaps four-fifths water, and that the ice crystals ran in every direction like shingle nails in a keg. Thin fingers and patches of surface ice were running on top of the water, but their crystals were in the horizontal plane, while in this anchor ice the crystals were noticeably different.

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SOME NOTES ON HOT-BATH TESTS FOR CEMENTS.

By FREDERICK H. LEWIS and J. EDWARD WHITFIELD.

READ SEPTEMBER 5TH, 1894.

WITH DISCUSSION.

On December 1st, 1886, a paper on cement testing, written by Mr. Henry Faija, M. Inst. C. E., was read before the American Society of Civil Engineers. In this paper Mr. Faija advocated the use of an apparatus which he called a "steamer," and which he claimed would reveal any "blowey" tendency in cements. The test consisted in keeping pats of cement in vapor and in water at a temperature of about 110° Fahr.

At a meeting of the Society on May 18th, 1892, W. W. Maclay, M. Am. Soc. C. E., presented a paper on hot tests for cements, in which he advocated the use of an apparatus which was exactly similar to that of Mr. Faija, as a means of discovering free lime in cement. Mr. Maclay, however, proposed to use a temperature but little short of the boiling point, or from 190 to 200° Fahr.

Between the dates of these two papers, the entire subject of accelerated tests for cements, hot-water tests, oven tests, Bunsen burner

tests, etc., was much discussed abroad, chiefly by Messrs. Candlot and Le Chatelier, in France, and by Messrs. Michaelis, Erdmenger and Tetmajor, in Germany.

More recently, at the Engineering Congress at Chicago last year, were presented the very interesting papers on cements by Messrs. Faija and Gary in the civil engineering section, and by Mr. Le Chatelier, before the mining engineers, together with their discussions. Each of these papers had something to say on hot-water tests of cements. Mr. Faija, we find, is in exactly the same place he was in 1886, and advocates the use of his steamer at 115° Fahr. as a means of detecting a "blowey" cement, expressing confidence that this temperature gives more reliable results than the higher one suggested by others.

Mr. Le Chatelier advised the use of an apparatus to discover the constancy of volume of cement in hot water.

Mr. Gary gave in detail the standard methods of testing cements in Germany. All hot tests are discarded in the German standards, for the reason, Mr. Gary tells us, that they have been found misleading. The test for constancy of volume is the thin pat in water at ordinary temperatures, precisely the same as the test recommended by the Committee of the American Society in 1884.

In the consideration of these opinions, the German decision against hot tests in specifications must evidently carry great weight. Because, in the first place, the Germans have studied cements, both theoretically and practically, in the most thorough manner; and, in the second place, because the German cements, as regularly manufactured, almost invariably withstand hot tests. As their competitors in England and America are very much less successful in this regard, the German opinion appears to be without commercial bias.

The writers of this paper have kept a hot-water apparatus in use and under careful observation for rather more than a year past, and have made during this time, in addition to regular tests, many experiments developing some points of interest, which it is their intention to present in this paper.

The hot bath and steam chamber have been kept uniformly at 180° Fahr. in a great majority of the tests. This temperature has been maintained by a Bunsen burner, with a constant pressure valve on the supply pipe. Occasionally only has the 115° Fahr. of Mr. Faija been used.

At the outset, the hot tests are interesting and convincing. The contrast is sharp between those pats which come out sound, firm and metallic, and those which show different grades of deterioration, varying from a few cracks to complete disintegration and rottenness; and the favorable impression produced by the sound pats is almost irresistible. If, therefore, this test can be shown to be really significant, it is a very desirable one.

In a course of experiments with lime, however, one is soon led to question whether free lime is not something of a bug-a-boo. It is quite true, as shown by Messrs. Le Chatelier and Maclay, that the addition of moderate percentages of caustic lime will cause swelling in pats placed in hot-water baths. But if hard burned lime is ground to pass through a No. 74 sieve, it soon ceases to be caustic. In a few days it is quite dead, and hydrates with little change of temperature. The fact, of course, is that in a powdered condition it rapidly takes up water from the air. It is probable, therefore, that in a week or ten days after grinding the free lime contained in a cement has ceased to be caustic.

Now, thoroughly hydrated lime is of no disadvantage to a cement. On the contrary, the strongest sand mortars are made up with mixtures of well slaked lime and Portland cement (see Candlot, page 220 to 224). Thus, in experimental tests by the writers, with a mixture of two-thirds Portland cement and one-third slaked lime, a mortar of 2 parts sand and 1 part of the cement mixture showed in test briquettes a tensile strength of 423 lbs. in seven days, and 583 lbs. in 28 days. Pats of this mixture of cement and lime also stood boiling tests perfectly, whether made up with fresh water or with sea water. We have also Candlot's authority for the statement that mixtures of small percentages of lime with Portland cements are much used in Germany to make cements more plastic. He says (page 221, "Ciments et Chaux Hydrauliques"):

"In Germany the use of mixtures of lime and cement has had a great development. The addition of lime to the cement is made in quite small proportion, and it serves only to give to the mortar a sufficient plasticity to be used with facility. A mortar composed of 1 part of cement to 6 or 7 of sand is often lean, little bonded and works difficultly; in a great number of cases, the resistance of such a mortar would, however, be quite sufficient; by adding a small quantity of lime in powder or in paste, the mortar is given the quality it lacks and becomes easy to use."

It follows, then, from these facts, that we need not care very much about free lime, if only it is well slaked.

Now it is a well-known practice in German cement manufacture, to make cements slow setting at will by the addition of sulphate of lime ; and it proves to be a fact that when cements are thus rendered slow setting they will in most cases at once stand boiling, although they had failed to do so when the set was quick. This fact was first called to the writers' attention by Mr. Thomas D. Whitaker, the president of the Whitaker Cement Company, and has since been quite fully established. Several brands of English and American Portland cements which would not "boil" when received, readily did so when made slow setting. Even a cheap grade of natural cement from the Lehigh Valley, which came out of the bath perfectly rotten when first tested, was found to be firm, hard, and stuck to the glass after a suitable addition of sulphate. Another natural cement, which had been rendered slow setting by sprinkling with water when drawn from the kiln, also stood the hot-bath tests admirably.

Not only is it true that cements can frequently be made to stand boiling by being made slow setting, but they will carry through the hot test a considerable added percentage of lime. Thus an American Portland cement, which at first would not "boil" satisfactorily, gave the following results on seven-day tests of neat briquettes :

No. 2 335	432 lbs.
" 2 336	463 "
" 2 337	503 "
" 2 338	449 "
" 2 339	475 "
Average	464 lbs.

This cement was then rendered slow setting, and 10 per cent. of quicklime was added as dry powder, and two briquettes were made from the mixture. The lime was ordinary hard burnt lime bought from a dealer and freshly ground for the test. The briquettes swelled and developed cracks in the moulds, but, after setting for 24 hours, were put in the hot water (180° Fahr.) and kept in it for 48 hours. They were then tested with results as follows :

Experiment No. 95	460 lbs.
" " 96	500 "

These broken briquettes have been lying on a shelf ever since (over three months), and are hard and sound with no signs of disintegration, except the original cracks mentioned above.

Another brand of American Portland cement which was quick setting gave the following results on seven-day tests of neat briquettes :

No. 3 085	500 lbs.
" 3 086	483 "
" 3 087	462 "
" 3 088	482 "
" 3 089	512 "
Average	488 lbs.

When made slow setting, 3 per cent. of quicklime, which had been specially calcined in a crucible at the high temperature of a steel furnace, was added. The briquettes were hard and sound, and after 24 hours were put in hot water at 180° Fahr. and kept at that temperature for 48 hours. They were then tested with results as follows :

Experiment No. 150	559 lbs.
" " 151	504 "
" " 152	598 "

Another portion of this second cement was then mixed with 10 per cent. of this steel furnace lime, which had been ground up fine and kept in a box in the air for a week. The neat briquettes came out entirely sound, and three of them gave the following results on seven-day tests, one day in air, six days in water :

Experiment No. 168	506 lbs.
" " 169	441 "
" " 170	446 "

Three other briquettes were put in the hot water at the end of 24 hours (180° Fahr.), and were kept in it for 48 hours and then tested with results as follows :

Experiment No. 186	421 lbs.
" " 187	420 "
" " 189	416 "

These briquettes showed a few small cracks on top, but no other defects. They have now been on the shelf for over two months, without change.

These results show the remarkable capacity of slow-setting cements to carry free lime, and to carry it without injury as far as present evidence goes, and of course it is thus evident that hot-bath tests do not reveal the presence of free lime in such cements. It may be said in reply to this that the free lime which does no harm need not concern us, and that the hot test is still good for the free lime which is injurious. But this claim begs the question. In Mr. Rudolph Dyckerhoff's discussion of Mr. Maclay's paper in 1892, he says that the test in no manner corresponds with practice, as fresh cement mortar is never exposed to hot water, and, he adds, "when thoroughly hardened, the mortar of any good Portland cement will safely pass this violent test."

Taken in connection with the tests set forth above, this very clearly explains the German position. From familiarity with the difference in behavior of cements, after being made slow setting, they have evidently reasoned that a quick-setting cement will either be able to deal with its content of free lime in ordinary course, or else its failure to do so will be manifested in cold water after the lapse of a few days. It is difficult to escape this conclusion; if a cement will not stand boiling in a fresh pat because of free lime, but will stand boiling in a pat a few days old, then it must in the interval have disposed of its free lime. The French authority, Mr. Candlot, substantially agrees with this view. He says (page 144):

"A cement of normal composition, not containing lime in excess, but in making which the burning has not been pushed to complete vitrifaction, swells enormously when immersed in hot water. Meanwhile, we have seen that such cements give in ordinary tests very good results, entirely different from those which are obtained from cements which contain an excess of lime. * * * * The mortars placed in sea water show no sign of alteration, and the test samples preserved in air give entirely satisfactory results. The test of the pure cement in hot water would meanwhile condemn such cements as containing an excess of lime."

As a test of free lime, the high-temperature bath has not, then, commended itself to the writers. Whether Mr. Faija's test at 115° is more satisfactory or not, they are not able to report from lack of

sufficient data. Such tests as they have made at 115° have been uniformly satisfactory with Portland cements.

It has been clearly suggested by some of the tests that there are other chemical factors of disintegration in hot tests besides free lime. Some cements are quite disintegrated in the hot bath, and one or two have failed to be entirely satisfactory after they were made slow setting. Analyses have showed these samples to contain high percentages of the anhydrous sulphate of lime; that is, the sulphate which is burnt in with the cement.

It is well known that the French specifications limit this anhydrous sulphate, and in all manufactures of cement there is an endeavor to keep it out of the product, although the reasons for this are not very clearly explained in the standard literature.

While, then, the hydrous sulphate which is added to cement after burning is not at all injurious in small percentages, the presumption is that the anhydrous sulphate is, and, as a working hypothesis, the writers have assumed that very bad pats are due to anhydrous sulphate. So far, the facts have confirmed this hypothesis, and a further investigation may lead to interesting results.

DISCUSSION.

R. W. Lesley, Assoc. Am. Soc. C. E.—The paper that Mr. Lewis and Mr. Whitfield have presented contains probably the latest information that we have on boiling tests for cement, and corroborates Professor De Smedt's and my own experiments. There is another side of the subject that has not been touched, and that is the fact that a great deal of this matter relative to the addition of gypsum, and of slaked lime to cement, and also relative to making it slow setting by water, is the subject of patents that were taken out a great many years ago, and which were preceded by many interesting experiments. In 1880 a patent was taken out by an Englishman, whose name, I think, was Jackson, who had invented an addition to the ordinary cements, making what he called selinitic cements. This patent consisted in the addition of gypsum to our ordinary natural cements, to make them slow setting, and, as he claimed, stronger. At that time I spent a great deal of time in investigating the subject in connection with Prof. De Smedt, the well-known chemist. We found that, while gypsum would make some cements more adaptable for immediate use, it gave the cement a

deceptive strength and a slower setting. It was tried with the quick-setting cement of the Potomac region, and, while it made the short-time tests higher, it had the effect of lessening the strength at long periods, especially in sand mortars. For this reason the patent never came into general use in natural cement manufacture. One manufacturer used it for a time and then abandoned it. Since then, however, the addition of gypsum to Portland cement, with the effects stated by Mr. Lewis, has come into use.

Another patent taken out in 1883 by Prof. De Smedt related to the making of quick-setting cements slow setting. It consisted in drawing out from the kilns the burnt material and sprinkling it with water. The theory is that by this moistening any small excess of caustic lime would be hydrated, and the cement rendered safe and slow setting. Chemical calculation by analysis is recommended to ascertain the percentage of caustic lime, and the proper percentage of water to hydrate the same is to be sprinkled by the use of a hose with fine spraying attachment. This patent I understand has been lately used without right by a number of natural and Portland cement works.

A third process, also patented, is the addition of slaked lime. There were a great number of experiments with this, and it was found that by the addition of slaked lime up to 15% the ordinary natural cement, as well as the Portland, is much improved. One theory upon which those experiments were conducted was that the setting of many cements is produced by the alumina, and that by adding slaked lime, which acted quicker than the alumina, the set is retarded and the cement is made marketable more quickly. The slaked lime also acts as a flux, making the mortar more plastic.

For the more successful use of the process of dampening or moistening the clinker or burnt stone, in 1884 I took out a patent for mechanically accomplishing the purpose by injecting steam or moistened air in the conveyor or elevator boxes. So much for the patents on this subject.

The difficulty about the boiling test that has always struck me is that no set of men, or no two men, can ever agree upon the exact method of this test. There is absolutely no agreement as to exposure, temperature or methods of testing. Since Mr. Maclay's paper and the reply to it which I made some three years ago, we have had the papers at the Chicago Exposition of Faija and Gary, both against the boiling test. It was also there that so eminent an authority as Mr. Whittemore said that the boiling test was of little value in determining the ultimate quality of cement. The German Society had this question up at their last meeting, and again adhered to the cold-water test. There Dr. Pruessing took up all the tests of heat and boiling, and, after recommending a modified boiling test of his own, stated that he had another test to recommend to determine the fresh

grinding of cement. This is to be done by placing a pat of fresh-ground cement mortar on an iron plate, heated to 392° Fahr. Then cold water is carefully poured on top until the pat is wet through and through, when it is again heated to 392° Fahr. Dr. Pruessing had the grace at least to admit that "in the test, by careless manipulation, the cake may tear without the cement being a checking one." No one who has ever as a child tried to bake mud pies will deny the accuracy of this last statement. In illustration of this, in a long series of experiments conducted in 1883 and 1884 in connection with the De Smedt-Willcox-Lesley patents for making Portland cement by dispensing with the intermediate process of brick making and drying of the slurry, it was found in every case where wet paste or wet brick were subjected to immediate heat a crust formed on the outside, steam or vapor formed on the inside, and that whenever this vapor forced its way to the surface it broke and destroyed the harder surface, and that a new surface formed as the process continued. This was overcome by mixing with the cement slurry, liquid hydro-carbons, which, by burning from the outside to the interior, formed pores, through which the interior moisture found a vent to the surface without destroying the latter. This process, improved by the adoption of heavy compressing rolls to make the slurry into egg-shaped balls well adapted to handling, was used for many years, and only abandoned when the introduction of water gas made the price of the coal-pitch combustible used in the mixture prohibitory.

Dr. Pruessing refers to the many accelerated tests which have gone before; the kiln test abandoned in England, and revised by Shepky; the glass test of Michaelis, in use 33 years, and rejected in 1876 by its inventor. He also refers to Heintzle's unsuccessful modification of this test, to Deval's hot-water test and Schumann's attack on it, and all other accelerated tests. He speaks adversely of the kiln and ball tests, which he says are "too uncertain," and then gives in table form results of some experiments of his own on 24 Portland cements, for the purpose of showing that his own method of testing is right and should be adopted. This method of testing and its results I shall refer to later, as, in my opinion, they do not prove what is claimed for them, but do prove that the ordinary cold-water test, in use here and in Germany, will, so far as change of volume is concerned, detect any imperfect cement.

The point that I am endeavoring to make is that, with these constant changes in these various grades of accelerated tests, it is difficult for the manufacturer, consumer or engineer to know just what is right and just what should be the standard. When it is considered that there are some 20 000 000 barrels of Portland cement made in every year, involving nearly $30 000 000, and that the great bulk of it is subjected to tests, it naturally becomes a very serious subject as to

what these tests shall be, and it is a very serious matter to take all this cement and subject it, not to well-defined, well-established and well-governed tests, but to a test which varies with the various differences of opinion between various men of various mental constitutions as to their opinion of temperatures, time of exposure and methods of testing. In view of all these differences of opinion and all these sudden changes that have taken place in accelerated testing for the last 25 years, the natural effect has been created that there is constantly a new set of tests coming out, and we must "wait for the latest," and when the "latest" comes, there is still the feeling that there is something to be later and more fashionable. For this reason, I again repeat, that in the face of the established tests in Germany, France, England and this country, none of which contain any of the accelerated tests, it is hardly a wise thing to make any change at this time; and several illustrations of the importance of this particular point have lately come to my attention, one of them in the city of New York.

On a piece of public work, a certain brand of cement is being regularly tested by the boiling test, and, as I am informed, has stood this test. Cement of precisely the same brand, made by the same works, shipped at and about the same time, was sent to two other large pieces of work in this same city. On both of these latter pieces of work, the ordinary cold-water test for checking of the American Society of Civil Engineers was in use. In both cases the cement failed, showing checking and cracking to a considerable extent. Certainly there is in this state of facts quite a commentary upon the effect of the boiling test.

In another experience, the manufacturer was informed by an engineer that the latter was going to boil some of his cement. The manufacturer quickly, for his own satisfaction, sampled the same barrel for the purpose of making in his own office similar tests. Within a few hours, he was at a leading testing laboratory with a serious expression on his countenance, and wanted a sample of the cement boiled at once, stating he had just been experimenting with this cement in his office, and had boiled it all to pieces. The testing laboratory took the cement and after two days of boiling in all the various methods known, were unable to make it check or crack. Differences such as this are occurring in daily practice.

In a third case, a cement which was largely used on an important work at Niagara, and which in most cases stands the boiling and yet is not manufactured with sulphate of lime with that end alone in view, had possibly the best actual boiling test within my knowledge. One of the plates over the firebox of a small movable boiler used by the contractor showed a crack. There was no time to repair it, and neat Portland cement was plastered over the crack. After it dried, a fire

was made, and for several days until the boiler-maker came, the cement stood the fire beneath and the boiling water above.

A further illustration is noted by Rudolph Dyckerhoff, Proceedings German Cement-Makers' Association, February 23d and 24th, 1894. He said, in commenting upon the accelerated tests then proposed for examination by the Society:

"When the boiling test first became known, I made, some 10 years ago, the following experiments with cements which had failed in the boiling tests and had stood the normal (cold-water) test. First, two pats were made from two cements. Of these, one pat after 24 hours' hardening in water and the other after 28 days' hardening in water, were duly boiled. The pats cooked after 24 hours' exposure were checked, but the 28-day pats remained good. Later on a great number of pats were prepared from various cements which had failed to stand the boiling test, and boiled after 24 hours, one, two, three and four weeks' hardening in water. After 24 hours' hardening, none of the cements stood the boiling. The longer, however, the pats were hardened in water, the better they stood the boiling water. Some stood it after two, others after four, weeks At periods over 28 days' hardening naturally, the pats of these cements stood the boiling. In later years I have repeatedly made similar experiments with various cements and received very similar results. I have also observed that if a cement is very strongly attacked by boiling after 24 hours' hardening, it requires more than four weeks' hardening to stand the boiling test. For instance, I received last year from London a sample of Portland cement which was ground very coarsely. A cake made of this cement was boiled after 24 hours' hardening, and checked, but it stood the boiling better each time after it had hardened one, two and three weeks, but even then the cake four weeks old was still full of cracks. Unfortunately, the quantity of cement in my possession was not sufficient for a larger number of cakes, but I am firmly convinced that, after a few weeks more, the cement would have stood perfectly the hot test. It may be mentioned that this cement as well as all the others I have discussed had stood the normal test. It seems clear that if a cement has stood the normal test, and does not stand the hot test at the stage of hardening, after 24 hours, but does stand this test after a longer period of hardening, such cement cannot contain any injurious lime; otherwise it would not stand the hot test ever so little at the later period."

Referring to the table of Dr. Pruessing, to which I have alluded above, his figures have an interesting bearing upon that portion of Mr. Lewis' paper, which is also substantiated by Dyckerhoff, and which refers to the fact that if a cement has not enough excess lime in it to cause swelling in the cold-water test, it will take care of any excess lime that it may have in it. The table in question was constructed for the purpose of demonstrating the value of the new accelerated tests of Dr. Pruessing. These tests he describes as follows:

"I take 100 drams of cement and from 5 to 7 parts of water, the amount of water depending upon the degrees of fineness of the grinding of the cement. The material is mixed until the cement has been thor-

oughly moistened by the water. It is then pressed into a cylinder mould and with the assistance of a power press is pressed into a round, sharp-edged cake."

In the table given herewith, the Pruessing tests are headed A, B, C, D, and are as follows:

A.—Pat 24 hours hardened in air, and 27 days hardened in water.

B.—Pat quickly put on an iron plate, heated to 392° Fahr., then wet throughout, and again heated to 392° Fahr.

C.—Pat after 24 hours' hardening in the air, then being placed for 2 hours in cold water, and then left for 24 hours at 194° Fahr.

D.—Pat 24 hours' hardening in air, 2 hours exposed to cold water, 27 days' hardening in water at 394° Fahr.

This table also contains practically all the accelerated tests that are well known, and also has a column devoted to the ordinary cold-water normal test of cement. As presented to the German Society, it also contains full records of the strength of the cement neat and in mortar, by tensile and compression strain, which are, however, omitted in the brief condensation of the table presented herewith, and bearing on the accelerated tests only.

By an examination of these tests, it will be seen that the one cement that shows the highest analysis in lime, to wit, No. 13, checked in the normal or cold-water test, as it also checked neat in nearly all the other tests to which it was subjected. It stood, however, in 3 to 1 mortar, the Erdmenger steam-pressure test, and neat it stood the Bunsen burner ball test. It is low in sulphuric acid, the slow setting being due to the excess of lime. It may be further noted that the cements which stood most of the accelerated tests were very slow setting, taking from 210 to 840 minutes to set, while those that failed to stand the accelerated tests were cements that took 8, 4, 300, 6, 70, 120, 35, 60, 10 and 840 minutes to set. It will also be noticed that those cements which stood the accelerated tests with the least advantage were those that showed (with only one or two exceptions) the coarsest grinding on sieves of 900 and 5 000 mesh per square centimeter. By a reference to the analyses of the various cements, it may be noted that in every case, with two exceptions, the cements which stood the Pruessing accelerated tests contained the larger percentages of sulphur as well as very much larger percentages of lime, thus showing addition of sulphate of lime. For purposes of comparison, I have tabulated herewith (see page 335), under the respective heads of "Stood" and "Failed," the various cements which stood or failed to stand the Pruessing accelerated tests, giving them by numbers and appending to each the percentages of lime, and sulphur, together with the time

	Fineness Residue on Sieves.		Percentage Water from Mortar.	Time of Setting. Min's.	Result German Normal Test.	Of the Tests for Permanence of Volume.							Erdmenger Steam Pressure Apparatus.		Analysis of Cement.		
									Pressing Test as Described.				Permanence of Volume.				
	900 M per sq. cm.	5 000 M.				Kilo Test.	Ball Test.	Steam Pressure Tests.	A.	B.	C.	D.	Pure Cement.	3:1 Mortar.	Ca O.	Mg O.	S O_3.
I..	1%	24%	29%	210	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.	*	*	64.80	0.95	0.22*
II..	1%	18%	28%	210	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.	64.48	Trace.	1.03
III..	1.5%	13%	28%	360	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.	63.60	1.01	1.64
IV..	6%	26%	30%	8	Good.	Good.	Small check	Good.	Bent, small check.	Checked.	Checked.	Checked.	Good.	Good.	62 80	0.95	0.49
V..	7%	33%	40%	4	Good.	Good.	Good.	Good.	Checked.	Checked.	Checked.	Checked.	Good.	Good.	62.88	Trace.	0.49
VI..	2%	19.5%	29%	195	Good.	Good.	Good.	Check free, but soft.	Good.	Good.	Good.	Good.	Check free, but soft.	Good.	64.08	Trace.	1.47
VII..	1%	16%	29%	540	Good.	Good.	Good.	Check free, but soft.	Good.	Good.	Good.	Good.	Check free, but soft.	Good.	63.60	Trace.	1.17
VIII..	4%	22.6%	30%	480	Good.	Good.	Good.	Check free, but soft.	Good.	Good.	Good.	Good.	Check free, but soft.	Good.	63.88	Trace.	1.19
IX..	8%	30%	30%	6	Good.	Good.	Good.	Check free, but soft.	Checked.	Checked.	Badly checked.	Badly checked.	Good.	Good.	64.30	Trace.	0.49
X..	1.5%	23%	29%	70	Good.	Checked.	Good.	Good.	Checked.	Checked little.	Checked.	Badly checked.	Good.	Good.	61.20	1.64	1.31
XI..	3.6%	23%	30%	15	Good.	Checked.	Good.	Good.	Good.	Good.	Good.	Good.	Check free, but somewhat soft.	Good.	61 10	1.27	0.63
XII..	8.5%	38%	30%	300	Good.	Good.	Good.	Check free, but soft.	Good.	Good.	Good.	Small check.	Check free, but somewhat soft.	Good.	62.96	2.05	1.10
XIII..	0.5%	16%	30%	120	Checked.	Checked.	Good.	Check free, but soft.	Check free, but soft.	Check free, but soft.	Check free, but soft.	Check free, but soft.	Check free, but somewhat soft.	Good.	65.20	1.74	0.67
XIV..	3%	23%	30%	35	Good.	Good.	Good.	Checked.	Good.	Checked.	Badly checked.	Badly checked	Checked.	Checked.	63.60	1.79	0.63
XV..	6%	27%	30%	840	Good.	Good.	Good.	Check free, but soft.	Good.	Good.	Good.	Good.	Check free, but soft.	Checked.	60.96	Not determined.	1.24
XVI..	12%	36%	28%	840	Good.	Good.	Good.	Very badly checked.	Checked.	Good.	Badly checked.	Very badly checked.	Badly checked.	Checked.	60.56	2.11	0.42
XVII..	7.5%	39%	27.5%	60	Good.	Good.	Good.	Very badly checked.	Badly checked.	Checked.	Beginning to disintegrate.	Disintegrating.	Check free, but soft.	Checked.	59.60	2.31	Not determined.
XVIII..	7%	32.5%	30%	10	Good.	Good.	Good.	Check free, but soft.	Checked.	Good.	Badly checked.	Disintegrating.	Badly checked.	Good.	59.52	2.33	Not determined.
XIX..	2%	27%	30%	540	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.	64.56	1.03	Not determined.
XX..	2%	28%	30%	600	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.			
XXI..	5%	20%	30%	345	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.	Good.	50.56	1.27	1.28†
XXII..	6.5%	35%	30%	660	Good.	Good.	Good.	Badly checked.	Good.	Good.	Good.	Good.	Badly checked.	Good.	59.74	2.68	0.88‡
XXIII..	4%	33%	30%	650	Good.	Good.	Bent, small check	Good.	Good.	Good.	Good.	Good.	Good.	Good.	64.18	1.40	0.56
XXIV..	2%	30%	30%	750	Good.	Good.	Good.	Badly checked.	Good.	Small check.	Very badly checked.	Bent, small check.	Badly checked.	Badly checked.	61.18	5.70	0.42

* 1. Not enough cement for these tests.
† XXI. Cement with large addition of furnace slag.
‡ XXII. Cement with small amount of furnace slag.

of setting. It will be noted that the average time of setting of those which stood these accelerated tests was about seven hours, while the average time of those which failed to stand the accelerated test was two hours; that the average lime of those which stood the accelerated test was 63.52%, while the average lime of those cements which did not stand the accelerated test was 61.93%, and that the average amount of sulphur in those cements in the table "Stood" was 1.01%, while the average amount of sulphur under the head "Failed" was 0.70%.

In the making of averages of this table, where the element of sulphur had not been calculated, as in Nos. 17, 18, 19 and 20, the figures of these samples are not taken into consideration in arriving at the averages of sulphur, and the same applies to No. 20, as to lime, where there was no analysis at all. No. 21, which is "largely adulterated with furnace slag"; No. 22, "small amount of furnace slag," and No. 24, with nearly 6% magnesia, are also excluded as abnormal cements. No. 13, which failed in the normal test, is also excluded. The conclusion, therefore, that I have arrived at from these tables is, that any Portland cement, even though it contains lime in considerable excess of what it should contain, to make the proper combination with the alumina and silica, may be made to stand the Pruessing, or in fact practically nearly any of the accelerated tests, by the addition of sufficient sulphate of lime mechanically ground with it. This conclusion is deduced from the figures given, showing that in nearly all the cements that stood these Pruessing accelerated tests, the lime, or lime and magnesia combined, were very high, the sulphur high and the time of setting slow. On the other hand, in nearly all those that failed to stand the accelerated tests, the lime was low, the sulphur low, and the time of setting quick, with the exception of the cases above referred to, where other elements entered into the calculation.

It is further to be seen that the only cement that contained a large percentage of lime, and that did not contain a large percentage of sulphur, but which was made slow setting by the large percentage of lime, failed to stand the ordinary normal cold-water test, thus corroborating Dyckerhoff's, Lewis's and De Smedt's views.

In view of this conclusion, it would seem from a careful examination of the history of cement testing and cement manufacture, that this method of treating cements with sulphate of lime came about substantially in this way. For many years manufacturers of Portland cement went on making cements of fair tensile strains at seven days neat and of fair average fineness. Later on, engineers began to demand higher tests neat at seven days and finer grinding, and the requirements of the old specifications of from 250 to 300 lbs. were run up to 400 and 500 lbs., and finer grinding insisted upon. This was all

done without reference to the fact that fine grinding tends to make the cement quick setting and low in tensile strain at seven days neat, though increasing its tensile strain in 2 to 1, and 3 to 1, sand mortars. The manufacturers, then, in order to meet these new requirements, soon ascertained that it was necessary to increase the percentage of lime in their cements in order to make these very fine ground cements slow setting enough to give high tensile strains neat at seven days, according to the requirements of most engineers outside of Germany. The increasing quantity of lime went on until it ran into the excess of lime, which the cold-water test began to discover. This led to innumerable discussions on free lime and over-liming, to detect which the various accelerated tests above described were brought out, in addition to the well-established normal test which had already discovered these incorrect methods of manufacture. To meet these accelerated tests and also the still higher requirements for neat tests at seven days, manufacturers began to test various modes of adulteration. Ground iron slag was the first, but it was soon exposed. It was followed by sulphate of lime, which is now largely ground with many Portland cements for the purpose of producing the results sought after, that is, to make the cement slower setting and higher testing in neat tests at short periods. This adulterant has only been in use for several years abroad and in this country. It is true that some manufacturers in America have used it for as long a period as a year or 18 months, but there are, so far as I can find in the books, no records of works done with cements in which this material has been used as an adulterant that have yet stood the long periods of time that the Portland cements made in the ordinary and approved way have stood, while it is well known that there have been a number of questions raised and referred to in the books, where the destruction of certain mortars used in salt water have been attributed to the sulphate of lime produced by the decomposition of the sulphate of magnesia in cements; as to this, Candlot, on page 253, states that in all cases where cement is kept in salt water, and the proportion of sulphate of lime exceeds 1 to 2%, the mortar never fails to show traces of alteration, and the briquettes are frequently completely disintegrated. On this point he refers to Mr. Feret's paper in the *Annales des Ponts et Chaussées*, March, 1890, page 67.

With this evident danger staring us in the face, the question is, is it wise for the manufacturer, in order to meet the innumerable accelerated tests that are proposed, to adulterate his cement with a material which leading authorities by repeated experiments have shown will, if used in any large amount, render it useless in salt-water construction? This question especially presents itself to the American manufacturers of Portland cement doing business with the coastwise cities of the United States, as well as to the foreign manufacturers supplying

the maritime countries of the world. It would be simply a reckless risk for a manufacturer to take, to use sulphate of lime in percentages over 1% as an adulterant of his materials, and especially for any manufacturer to put such cement on the market, unless he had assurance from each and every party purchasing his material, that it would not be used in salt-water construction.

Stood.				Failed.			
No.	CaO.	SO_3.	Time of Setting. Minutes.	No.	CaO.	SO_3.	Time of Setting. Minutes.
I.....	64.80	0.22	210	IV.....	62.80	0.49	8
II.....	64.48	1.03	210	V.....	62.88	0.49	4
III.....	63.60	1.64	360	IX.....	64.30	0.49	6
VI.....	64.08	1.47	195	X.....	61.20	1.31	70
VII.....	63.60	1.17	540	XII.....	62.96	1.10	300
VIII.....	63.88	1.19	480	XIII.....	65.20	0.67	120
XI.....	61.10	0.63	15	XIV.....	63.60	0.63	35
XV.....	60.96	1.24	840	XVI.....	60.56	0.42	840
XIX.....	64.56	.....	540	XVII.....	59.60	.....	60
XX.....	.....	.....	600	XVIII.....	59.52	.....	10
XXI.....	50.56	1.28	345	XXIV.....	61.18	0.42	750
XXII.....	59.74	0.88	660				
XXIII.....	64.18	0.56	650				
	63.52	1.01	421		61.93	0.70	148

Thomas D. Whitaker, Esq.—I think this question of hot-water tests has considerable value, at least to the manufacturer. Mr. Faija has given this subject more time and study than anyone else, and still approves of a hot-water test, though somewhat moderate compared with the one in Mr. Lewis's paper.

We have used this hot-water test for a long time at our works, and I consider it a good test for the manufacturer. I do not, however, advocate it for the practicing engineer, for I think in many cases it may condemn a good cement; but the manufacturer, who knows his own cement and how it stands the hot-water test when in its normal condition, can easily distinguish any change that may take place in it by noting its behavior when subjected to this test, for its great advantage is its very marked results.

I think Mr. Lewis, in his paper, uses some terms improperly, for example, "free lime"; he does not designate any difference between free and hydrated or carbonate of lime. I take free lime always to mean caustic lime, and I believe this is the correct meaning of the word. I cannot see how we can call carbonate of lime in cement free lime, for it is combined with carbonic acid and is not detrimental beyond the amount of impurity it adds to the cement, whereas the caustic lime will swell by the addition of water and cause the cement to crack, and, if in suffi-

cient quantity, will cause complete disintegration. It is well known that the longer or harder lime is burned, the greater time it will take it to slake, so in a well-burnt Portland cement, any free lime that is present will be very hard burnt, and consequently will be very slow to slake, so after the cement has set or taken its form and commenced to shed the excess of water, that water will be taken up by the free or caustic lime, and when it begins to slake it will swell and break apart the bond in the cement and cause cracking and disintegration. It is also well known that hot water will cause this slaking of caustic lime to take place much more rapidly and this is the theory upon which this test is based.

In the matter of the addition of sulphate of lime to Portland cement I have experimented largely, and have found the addition of sulphate of lime in small quantities to be beneficial. These tests and experiments were carried on for more than a year, and the cement has improved in test up to that time, and in no case has there been any indication of disintegration or decrease in tensile strength, except when the experiments were carried on with sea water. In that case I found that a very small quantity of sulphate of lime should be used, as a small percentage would cause disintegration on account of the chemical action that takes place between the sulphuric acid and the alkalies of the sea water, and I do not think the limit of 2% of sulphuric acid in Portland cement too severe, for I believe an excess beyond this amount to be detrimental, especially if used in sea water. In ordinary tests, however, I have tried double this amount with apparently no detrimental effect.

Did I not understand Mr. Lesley to say that the cement that contained the greatest amount of free lime passed the hot-water test?

Mr. Lesley.—No, it was detected in the cold-water test; I did not say free lime, but the highest in lime, and it contained 66 per cent.

Mr. Whitaker.—I thought you said free lime. I was going to ask you how they determined it, for I don't think anyone here knows how, and it certainly would be of interest to us to know. You spoke of these cements being high in sulphuric acid by the addition of gypsum.

Mr. Lesley.—I say they were made slow setting by the addition of gypsum.

Mr. Whitaker.—Could you give us those percentages?

Mr. Lesley.—Certainly, sir; you can see them in the table referred to.

Mr. Whitaker.—They were all German cements, were they not?

Mr. Lesley.—They were 24 German cements, so far as I am informed.

Mr. Whitaker.—In English cements I do not think you will find any with less than 1 or 2% of sulphuric acid. The American cements will average about 1¼ to 1¾% of sulphuric acid.

Near the close of Mr. Lewis's paper he says that the disintegration of the cement in hot water is undoubtedly caused by the anhydrous sulphate of lime, that is, the sulphate of lime that is burned with the cement. I have experimented on that, and I must say I differ with Mr. Lewis. I have had cement that only showed $\frac{3}{10}$ of 1% of anhydrous sulphate of lime entirely fail in hot water, while others containing a much larger amount stand it perfectly. I have tried different percentages of lime, silicon and alumina in the composition of the cement, and found that as soon as the lime was somewhat low and the alumina high that the cement did not stand the hot water properly. My theory for this is that alumina is said to give an acid reaction when heated to a high temperature, for we burn our cement at a very high temperature (we use oil fuel in our kilns and get an exceedingly intense heat). The excess of alumina will need more lime for its combination, and there will not be sufficient lime remaining to combine, as tri-calcium silicate, with the silicon. The excess of silicon, having a greater affinity for the alumina than the lime, will rob the lime of its alumina, fluxing with it and leaving the lime in a free state. This is theory on my part, but I cannot account for this condition in any other way. And so I am convinced from my experiments so far, that the hot-water test does act on the free lime. I do not think it is on the aluminates of lime, and I again state that I think the hot-water test a good one for the manufacturer, and after 18 months' use at our works we still propose to continue the use of it, and can tell the least variation of our compound by its behavior in hot water.

Mr. Lesley says: "The cements which stood all the tests were very slow setting." Since this remark I have made some tests of exceedingly slow-setting cement without the sulphate of lime. It did not stand the hot-water test, and the addition of sulphate made it rather quicker setting, and it gave no better results in the hot water, although it was an exceedingly good cement, taking from four to eight hours for initial set, and showing about 700 lbs. tensile strength per square inch for a test of neat cement in a week, and 200 lbs. tensile strength per square inch, 3 parts of standard sand to 1 of cement in the same time. These are certainly good results, but this cement undoubtedly contained free lime, although not in sufficient quantity to be detrimental, but too much to stand hot water. I am still experimenting with this cement, and believe that it will lead to some very interesting results.

Robert A. Cummings, Assoc. M. Am. Soc. C. E. (by letter).—To the numerous essays on the subject of cement, concrete and kindred subjects, is added this paper on "Hot-Bath Tests." It is in a direction of research which is very inviting, and, judging from the abstract of the paper, very encouraging. It would be unwise to travel the ground of published comment, but the views of the authors may be elicited on a few questionable matters.

"There is at present only one way of determining whether the judgment passed on a cement by any system of testing is sound, and that consists in waiting half a century to see how the work stands," says Mr. M. H. Le Chatelier, in discussing the hot-bath tests.*

It is of paramount importance, therefore, to develop any method by which practical cement testing can be more rapidly carried out. This is especially the case with the hot-bath tests method.

There is an obvious advantage in having the chemical analysis of cement determined, and to the practicing engineer the immediate knowledge of the strength and quality of the cement on the work is of primary importance. It is well known there may be a variation of 25% or more in the tensile test method by different experimenters which is sufficient to warrant its condemnation.

The writer's experience has satisfied him of the necessity for careful manipulation of cements in testing by experts alone, whose qualifications command the confidence of engineers and manufacturers alike.

In hot-bath tests the precise and thorough mixing of the ingredients has been found necessary, to produce compactness and freedom from air bubbles which materially affect the result. Cement mortar mixed as dry as possible will occupy a much greater volume than the same quantity mixed with the proper proportion of water. The driest cement mortar will therefore be less compact.

The writer would endorse the views of the authors as to free lime, with the precautionary exception that improperly burned cements must not be overlooked. The unfortunate existence of free lime in certain work to the writer's knowledge is sufficient evidence of its importance and the necessity for its detection.

In a properly burned cement, made with the ingredients thoroughly mixed, there is no free lime. It may be advanced that the expansion of cements is due to the fine particles setting first and the coarse grains taking longer, or being incompletely hydrated. This may be the case with certain cements, and it would substantiate the necessity for uniform fineness in quality. The specific gravity of new cement will determine whether or not it has been insufficiently burned, and should therefore be embodied in all tests.

Why were not the hot-bath tests made at boiling point, which is easier to maintain than 180°?

Did the authors use distilled water in their tests? If not, the soluble constituents of the local supply might account for some results.

The microscopical examination of the cohesiveness and conduct of cements opens a field upon which the authors may have some information.

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* *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, 1890, p. 560.

Now that hot-bath tests indicate the quality of cement in a more or less degree, one is led to inquire what will low temperature or alternate freezing and thawing tests indicate?

It has long since appeared to the writer a somewhat one-sided conduct to have our metallic materials precisely specified and inspected by experts at the manufacturer's, while cements are frequently received on the work, without having any idea where they come from, their quality or age. The mechanical function of testing so many thousand briquettes in tension is performed by a promoted rodman, and "All's well that ends well!" so far as he knows.

It is needless to say there is a much-needed reform for the consistent management of this department, and the authors have done good work in bringing the matter forward so ably.

M. J. Butler, M. Am. Soc. C. E. (by letter).—Shortly after Mr. Faija's paper appeared the writer began to make use of the hot-bath test, and from that time on has always relied on it as being the surest and safest way to determine the soundness of a cement. It is believed by the writer that with a set of sieves 2 500, 5 476, 10 000 and 22 500 meshes to the square inch, for the purpose of ascertaining the fineness, a specific gravity determination apparatus and the hot bath, one can arrive at a safer conclusion as to the soundness and suitability of a Portland cement than by any other known means.

There can be no doubt that the hot test is being abused; excessive temperature will probably blow any coarsely ground chemically perfect cement; hence, in the absence of a test for fineness it may be misleading to that extent. Manufacturers of cement, knowing their cements will be subjected to the boiling test, are in self-defence compelled to keep down the percentage of lime with a consequent reduction in tensile strength; but any properly burned, properly ground Portland cement, containing 60% of lime, will stand the hot test, as laid down by Faija, although if fresh from the stone will probably blow if boiled. The authors seem to have discovered a useful part for sulphate of lime as a factor in cements.

William H. Booth, M. Am. Soc. C. E. (by letter).—I wish to say that I am in agreement with the authors as to the terrors of free lime in cement. Suitable air slaking will purge a cement of caustic lime and render it safe. Free or caustic lime may be rendered safer by fine grinding, which reduces the particles to flour and so evenly distributes them throughout the bulk of the cement as to render them easily hydrated, even if not perfectly air slaked. So far, however, as English cement is concerned, the whole of the manufacture is carried out upon low-lying, often marshy, land, near tidal rivers, in a humid atmosphere, and the process of air slaking is fairly rapid.

Until quite recently it has been the habit not to grind so finely in England as in Germany, perhaps in part because of the greater safety

arising from a humid atmosphere, and partly because of the superiority of the English raw material; but owing to German competition, the English makers are grinding finer, and I have no difficulty in getting cement ground to pass through a No. 80^2 sieve. I am aware of the addition of sulphate of lime to promote slow setting. This addition is made by the German manufacturers to meet American specifications, but it is not looked on here as an honest cement, and, if above a small percentage, will make a cement unsound, and it ought to be rigidly excluded. A pure cement ground from a well-burned clinker of a proper mixture of the simple raw materials, chalk and clay, will be a sound cement, for there is no impurity in the above two substances which will render a cement unsound. If ground from clinker that has not been picked over to remove portions insufficiently burned, there is, of course, introduced a foxy colored, quick-setting element which is, perhaps, unsafe, but such can only arise from simple neglect. The half-burned clinker only costs the wages of picking out, for it can be further burned in another kiln. I am, therefore, in very full agreement with the authors that sulphate of lime is a mischievous and improper adulterant. Indeed, anything added to a cement makes it worse, and engineers would do well to guard themselves against drawing such specifications as lead to adulteration, for it is to the impossible clauses in specifications that the sulphate mixture is due. What is known as the "first" set of a Portland cement is undoubtedly due to the presence of more lightly burned clinker. That a little may creep in as dust is, of course, unavoidable, and, so far, is of no serious harm, the slight initial set being an advantage; but there should never be so much present as to destroy the blue color of the cement.

L. C. Sabin, Assoc. M. Am. Soc. C. E. (by letter).—Several points touched upon by Messrs. Lewis and Whitfield are of much interest to users of cement. The following conclusions seem to be presented:

First.—That when free lime occurs in a cement it ceases to be caustic in a week or ten days.

Second.—That "thoroughly hydrated lime is of no disadvantage to a cement," but rather an advantage.

Third.—That if a defective cement is rendered slow setting by the addition of sulphate of lime, the hot test will not then detect its defects, even though these defects be accentuated by the addition of free caustic lime to the already unsound product; and hence—

Fourth.—The high-temperature bath is not of much value in detecting free lime.

The first conclusion seems to be based on the fact that when ordinary lime is ground to a powder it quickly hydrates, or slakes, in the air. The length of time required for lime to slake depends on its

purity, and the degree of heat to which the more or less impure raw material has been subjected in burning. It seems, then, quite conceivable that the "free lime" in cement may not slake in the air, or even in water, in anything like such a short length of time. This idea is not new.

That hydrated lime is of advantage to a Portland cement is an idea that is not only new, but one which, it is believed, will have to be supported by very substantial evidence before it is generally accepted. Mixing lime paste with lean Portland cement mortars is often recommended for reasons purely mechanical, but it is generally considered that replacing a portion of the cement with lime results in a proportionate decrease in strength. While it may not be actively injurious, it is not clear how hydrated lime can be considered anything but an adulterant as far as strength is concerned.

The third point mentioned above is one which, if proved to be true, is of great interest and importance. If a cement which is defective on account of free lime may be made to withstand the hot-bath test by the addition of sulphate of lime, it will detract very much from the usefulness which the hot test is supposed by some to possess. The first tests cited in the paper to prove this point show that after being rendered slow setting, the cement under consideration would not bear the addition of 10% of quicklime even when the cement mortar was left in the air. There would scarcely be a necessity then of resorting to the hot test. The briquettes apparently expended all their expansive energy in the molds, and when subsequently placed in the hot bath they developed some strength. This is analogous to the action of frost on mortars; the freezing of the water in the mortar may cause swelling and cracking, but with the approach of warm weather considerable strength may be developed. Concerning the tests numbered 3 085, etc., and 150, etc., the cement withstood the hot test after the addition of 3% of a hard-burned quicklime. By referring to Table III of Mr. Maclay's paper,* it will be seen that the hot test did not detect a 3% addition of lime if the pat was not immersed within less than 24 hours after being made. It was not surprising, then, that these briquettes withstood the treatment to which they were subjected.

As regards the remaining briquette tests it may be noticed in passing that the seven-day cold-water test did not give any indication of the very large amount of lime present. If this lime were of the kind mentioned in the early part of the paper as requiring but seven to ten days to slake, it is not strange that the cold test failed to show it, since the lime had remained in a box for a week; neither should the hot test be expected to detect it, as I have not seen it claimed by any writers on the subject that the hot test would detect hydrated lime.

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* *Transactions* Am. Soc. C. E., Vol. XXXVII, page 418.

But a possible explanation of the failure of the cold test and partial failure of the hot test to detect the large amount of lime may be found in the nature of the latter as regards impurities and degree of burning. If the writers were able to show by subsequent results that this lime was such as to render the cement a dangerous one to use, or that the lime used was in the same state as that which is found in cements, then it might be said that the hot test should have brought out the defects of the cement more clearly. The "remarkable capacity of slow-setting cement to carry free lime without injury" does not, therefore, seem to be very clearly established, if "free lime" is taken in its ordinary meaning in this connection.

Neither is it quite plain what "question" is begged by saying that the free lime, which does no harm, need not concern us. What is usually claimed for hot tests is that they will detect tendencies to change in volume, and it is generally believed that free lime (not hydrated) is one of the most common causes of swelling. It is clearly stated by most writers that free lime is not the only cause of swelling.

In testing Portland cements, I use a temperature of 80° Cent. for hot-bath tests. This is practically the same as that used by Messrs. Lewis and Whitfield. This may not be the best temperature. It is possible that it might well be increased to a point somewhat below 100° Cent., and it may be that the temperature used by Mr. Faija is sufficiently severe.

The following results were obtained with a sample of cement which failed in the cold-pat test. A thin pat on glass, placed in cold water (15 to 18° Cent.) when it had set, cracked slightly at the edges in about two weeks, and a similar pat treated the same way, except that it was left two hours longer in the air, cracked in about four weeks. Two pats which were left in the vapor three hours and then immersed in the hot bath (80° Cent.) showed many fine cracks on the surface, had warped and one of them had nearly disintegrated in less than four days; these two pats were placed in the vapor when they would hold the ¼-pound wire and 1-pound wire, respectively (General Gillmore's wires). Some of this cement was then spread about 3 ins. deep, and placed in a dry place to aërate. At the end of one, two and three weeks the tests were repeated on the aërated sample with little, if any, better results. At the end of nine weeks' exposure, a treatment to the hot bath for two days showed that pats would not yet withstand the hot test, but in cold water one of the pats was still sound after two months, while the other was only slightly warped. After 15 weeks' aëration, the pats merely became detached from the glass after being in the hot bath two days. The following results were obtained with briquettes from this sample of cement, 2 parts sand to 1 cement, by weight. The hot-water briquettes were in moist air 21 hours; vapor, three hours;

and hot water (80° Cent.), four days. The cold-water briquettes were in air 24 hours before immersion :

Time aërated, days.	Temperature of water of immersion.	Age, days.	Mean tensile strength in pounds per square inch.	Swelling of 1-in. section.
00	80° Cent.	5	8	$\frac{1}{8}$ in.
21	"	5	18	$\frac{1}{10}$ "
63	"	5	186	
00	15 to 18° Cent.	7	258	
00	" "	28	368	

It may be held by some that the checking of neat cement pats, even in cold water, does not prove that the cement may not give good results when mixed with sand, and consequently that I have not shown that the cement under consideration is a bad one. However, I submit that it would not generally be thought that the manufacturer had been treated unfairly if such a product were rejected. I do not believe an engineer would get his full allowance of sleep if he thought his structure rested on that cement, yet a tensile test five months, neat, cold, showed a strength of about 540 lbs. per square inch, with no cracks visible in the briquettes. Had this cement been stored long enough to have aërated about the same amount as it did in nine weeks, when spread out, then before the two months required by the cold test to detect a tendency to blow had expired, the cement would doubtless have been in the work. As the hot-bath test showed this tendency in two days, I leave it as an open question whether it gave any useful information.

As is intimated above, there are but few who would not pronounce this sample unsound. As aëration improved its quality, the unsoundness might have been connected with the presence of free lime ; if so, the latter would not appear to be such a harmless element, and this free lime required more than 10 days to slake.

It has seemed to me that the promoters of the hot test have made greater claims for it than were warranted by the results which they have presented, and it is certain that inconsistencies exist which furnish points of attack for its detractors. Mr. Henry Faija has been satisfied with the results of his apparatus with a temperature of about 115° Fahr., after many years' use, but there are probably many engineers who have used the cold test alone, and have not met with any failures in their work which they attribute to unsound cement. In his paper on the subject Mr. Faija says :* "Some cements will blow whether they are new or old"; and again (page 59): "That nearly any cement that had aged sufficiently would stand the hot test"

* *Transactions*, Am. Soc. C. E., Vol. XXX, page 56.

(referring to 80° Cent.). Now, it seems certain that a cement which stands the hot test will also stand Mr. Faija's test, and hence his test would fail to detect tendencies to blow in those cements which were old.

The value of the hot test should be demonstrated by an extended series of experiments. It is not sufficient to compare the results obtained in the hot bath with 7 and 28-day results obtained in cold water. Before the hot test will be generally accepted, it must be shown that a cement which withstands this severe treatment will not prove defective in ordinary use after months, at least; and in justice to the manufacturer, it should be shown that there is not a large class of cements which will give the best results in practice but which will fail in the hot tests. But "Rome was not built in a day." Meantime, that the hot test is gaining in favor is evidenced by its extending use, and such papers as the one under discussion are very welcome, as elucidating the subject.

W. W. Maclay, M. Am. Soc. C. E. (by letter).—I have carefully read the paper by Messrs. Lewis and Whitfield without finding any reason to change my views about "Hot Tests for Portland Cement," as set forth in my paper*; on the contrary, I am to-day more strongly in favor of the "hot tests to quickly show the tendency of Portland cement to change its volume" than I was two years ago. My reason for feeling more positive than formerly in regard to the usefulness of the hot tests is because I have employed this test almost constantly since my paper was read, and always with satisfactory results. By this I mean that Portland cements that failed by exposure to the air for long periods, from three months to one year, by losing their early tensile strength or by disintegrating entirely, were invariably rejected in 24 hours by the hot test, and invariably passed all the cold-water tests. Great weight is always given in the discussions against the "Hot Tests for Portland Cement," to the fact that the German Normal Rules for testing do not recognize them. This fact would almost seem to settle the question against the hot tests, inasmuch as Germany is acknowledged to be the foremost country in the manufacture and testing of Portland cement. The opinion in Germany, however, against the hot tests is not nearly so unanimous as is commonly represented; some of their most eminent cement engineers are not only in favor of the hot tests, but are using them at the present time in addition to the Normal Rules, and, as for the manufacturers, I think there are few that do not now use the hot tests for their own information, whatever may be the practice with the consumers.

There will be a conference or congress of eminent cement engineers of different nationalities at Zurich, Switzerland, in September, 1895, where the whole question involving the change of volume of Portland

* Vol. XXVII, *Transactions*, Am. Soc. C. E., October, 1892.

cement will again be thoroughly discussed, and recommendations made; and, inasmuch as the German Normal Rules have been largely the result of these congresses, we need not consider the question as definitely settled against the hot tests quite yet.

The following is an extract from a paper sent to me by Dr. Michaelis, of Berlin, early in the present year :

"The so-called American hot-water test, described in No. 12 of the *Thonindustrie Zeitung*, of March 18th, 1893, has been, as it is known, but with slight alterations, used by me for many years. I always recommend it for the purpose of selecting the most reliable cement in the shortest time. Therefore I welcome the impartial experiments on this method by the American engineer, W. W. Maclay, and his colleagues in the field."

"For ten years I have endeavored, but without success, to prove the value of an accelerated testing of Portland cement to the Ministry of Public Works in Prussia. Alas, it is unfortunate to be so far ahead of the age. At the present time the chances look somewhat better."

The writers of the paper under discussion are inclined to think the question of free lime a "bugaboo," and argue that because hard-burned lime ground to pass a No. 74 sieve soon ceases to be caustic, and rapidly takes up water from the air; therefore, it is probable "that in a week or 10 days after grinding, the free lime contained in a cement has ceased to be caustic." This theory may seem plausible to the writers, but it is not very satisfactory to the manufacturer who finds himself obliged to cure his cement six months before he dares to put it on the market.

Some space in the paper is devoted to proving that hydrated lime is of no disadvantage to a cement. This, of course, admits of no discussion, for as soon as the free lime in a cement has been hydrated, it will pass all hot tests.

The addition of small quantities of sulphate of lime to properly burned and carefully proportioned artificial Portland cement to make it slow setting has long been practiced in the German factories, and doubtless enables some of their cement to pass the hot tests, which they would not do before the sulphate of lime was added. But to follow this practice with a really objectionable Portland cement, containing a large excess of free lime, would require the addition of sulphate of lime beyond the recognized limit.

The effect of adding caustic lime to Portland cements, given in Table I of my paper, already referred to, does not agree exactly with the results recorded in the paper under discussion, but this may be due to the fact that some of the lime used in these experiments "had been ground up fine and kept in a box in the air for a week," when, of course, it would cease to be caustic.

Mr. Rudolph Dyckerhoff, in discussing my paper in 1892, is quoted in this paper as saying:

"When thoroughly hardened, the mortar of any good Portland

cement will safely pass this violent test," and the writers of the paper go on to say from this, "It is difficult to escape this conclusion—if a cement will not stand boiling in a fresh pat because of free lime, but will stand boiling in a pat a few days old, then it must in the interval have disposed of its free lime."

Mr. Dyckerhoff's conclusion quoted above, and the writer's deduction therefrom, are both erroneous, as well as the remarks, in this connection, made by Mr. Dyckerhoff at the general meeting of cement manufacturers in Germany in March, 1893, viz.: "What, in fact, is meant by a cement not standing the boiling test? Nothing else, but that the cement mortar at a certain state of its hardening, after 24 hours, does not resist the boiling water; after a longer time, say, 14 days, the very same cement will endure the boiling test, etc." My own experience is exactly the reverse of Mr. Dyckerhoff's. Cements that would not stand the boiling test at 24 hours after gauging I have kept from three to four months immersed as neat briquettes, and even after that long interval of immersion in normal cold water these briquettes still failed to pass the boiling test. Pats and briquettes from these cements, kept in the air, cracked and disintegrated after two or three months' exposure, although the normal cold tests for short and long periods gave excellent results. It was, therefore, very gratifying to receive from Dr. Michaelis a paper completely confirming my own experience and refuting the views of Mr. Rudolph Dyckerhoff in this connection. The following is in Dr. Michaelis' own words: "In 1875 the undersigned (Dr. Michaelis) found with a South German Portland cement, renowned for its remarkable strength in common water hardening and not showing any increase of volume or decomposition in the air, that the briquettes which hardened and remained sound for months in the water were totally destroyed after but half an hour's boiling. Any cement that is not perfectly constant in volume and that shows an increase of volume 24 hours after the pats are made and boiled three or four hours will show the very same after 2, 3, 7 and 14 days of hardening (the first day in moist air, and after that under water), when they are afterwards submitted to the boiling test. Of course this can be changed by seasoning the cement from 7 to 14 days before making up the test pat and submitting it to the boiling. The boiling is not intended to prove whether the cement will be constant of volume in future time, but whether it is so when mixed and tested."

"Mr. Dyckerhoff will probably change his opinion after thoughtful study of the boiling test.

"On the other hand, it has been proved to be wrong, when Mr. Dyckerhoff says, 'Every Portland cement standing the standard test for constancy of volume will, in practical use, even at normal temperatures up to between 104 and 122° Fahr. (40 and 50° Cent.), prove always constant in volume for all future time.'"

I think, therefore, that while the writers of this paper are technically right in giving considerable weight to the German decision against hot tests, on the other hand, the friends of the accelerated tests need not despair of their views being almost universally accepted

at some future time, when they count as they do now, some of the ablest cement authorities in Europe as their advocates.

Messrs. Frederick H. Lewis and J. Edward Whitfield.—The following experiment is perhaps more convincing than anything which has yet been said, viz.: Take freshly ground and quick-setting cement and treat it with 2% of sulphate of lime, using preferably what is known as boiled plaster. The cement will at once become slow setting, and in nearly all cases it will at once stand the boiling test. Now take the sample thus treated and spread it in a shallow box, freely exposed to the air, so the free lime present can take up moisture and carbonic acid, and then test the cement every few days, to ascertain its setting time. It will be found that the time becomes shorter and shorter, until, at the end of two or three weeks, the cement is nearly as quick setting as it was before the plaster was added. When the cement has reached this condition, add to it 2 or 3% of quicklime, and again test the setting time. It will be found that the cement at once becomes quite slow setting again.

The explanation of these phenomena is simply this, that the cement can be slow setting only in the presence of quicklime. This may fairly be called *reductio ad absurdum* for the boiling test for free lime, because it is demonstrated that the sulphate has no effect whatever upon the lime, but that its reaction is with the aluminate of lime. As in many other chemical reactions, the presence of free lime is merely auxiliary. We owe these facts to Candlot, who developed them in an elegant series of experiments.

Now, no prejudice in regard to cements is more widespread than that the quick setting is due to the presence of lime. It is generally assumed that this is a self-evident truth, axiomatic. Yet Mr. Lesley points out that the addition of lime to cements has been practiced commercially, for the purpose of making it slow setting, and it is a very simple experiment to demonstrate that the addition of a small percentage of quicklime will generally retard the setting, and sometimes, as noted above, will produce a marked difference in the setting time.

It can hardly be questioned that the prejudice referred to accounts for the ready reception of the boiling test. When an experimenter finds that the quick-setting cements generally fail in this test, its value is at once established, because he knew (?) beforehand that the quick-setting cements contained free lime.

Mr. Whitaker objects to the use of the term free lime, and the writers in a measure agree with him. The word lime means, both in common and scientific use, calcic oxide (CaO), quicklime; or its hydrate ($CaOH_2O$), slaked lime, and nothing else. But just what is meant by "free lime," used in connection with the boiling test, we should prefer to leave for explanation to its advocates. It has always

seemed to us that Mr. Faija was more modest, and perhaps much more accurate also, in simply claiming for his apparatus that it would detect a "blowey" tendency in cements.

Covering the questions raised by Mr. Sabin on the propriety of using mixtures of Portland cement and slaked lime, we give below the records of tests by Candlot, referred to in the original paper.

First Series.

Composition of mortars for 1 cu. m. of normal sand, weighing 2 870 pounds.		Per cent. of water.	Tensile tests of briquettes, in pounds per square inch.				
			7 days.	28 days.	3 months.	1 year.	2 years.
1 215 lbs. of these different mixtures of lime and cement:	Cement, 80 / Lime, 20 ..	11.0	223	300	424	537	512
	Cement, 65 / Lime, 35 ..	12.5	207	285	363	514	455
	Cement, 45 / Lime, 55 ..	13.0	145	205	322	469	425
	Cement, 30 / Lime, 70 ..	13.0	121	185	286	368	375
Weights of a mixture of 70% cement and 30% lime for 1 cu. m. of sand (2 870 lbs.):	550 lbs.....	10.0	78	134	158	213	219
	990 "	10.0	201	269	322	478	482
	990 " (air)...	10.0	235	370	441	533	766
	1 440 "	10.0	334	357	488	585	636

Second Series.

Composition of the mortars.		Tensile tests of briquettes, in pounds per square inch.					
		7 days.	28 days.	3 months.	6 months.	1 year.	2 years.
Cement, 90 / Lime, 10	1 part to 3 sand	229	310	377	397	415	451
Cement, 80 / Lime, 20	" "	200	283	328	361	420	435
Cement, 70 / Lime, 30	" "	139	193	252	297	318	371
Cement, 60 / Lime, 40	" "	122	175	226	276	306	320
Cement, 100 / Lime, 0	" "	142	229	292	368	377	437
	" " (air)..	132	229	296	446	577	711
	" 5 "	67	91	148	148	180	202
Cement, 70 / Lime, 30	" 3 "	162	218	295	401	390	454
	" 3 " (air)..	202	255	361	352	484	484
	" 5 "	80	107	128	166	178	215
Cement, 60 / Lime, 40	" 3 "	148	192	238	277	308	425
	" 3 " (air)..	169	277	385	344	458	727
	" 5 "	.....	90	116	134	155	199
Cement, 50 / Lime, 50	" 3 "	85	116	162	159	193	269
	" 3 " (air)..	108	201	267	222	378	660

It would appear from the way in which the mixtures are described in the first table that these tests are actually mortar box tests. It is, of

course, essential for good results that the lime shall be thoroughly slaked.

Speaking of slaked lime, is it not a fact that free and uncombined slaked lime is, and must always be, found in cements? The prime factor * in Portland cement is: SiO_2. 3CaO; and the reaction with water is SiO_2, 3 CaO + aq. = SiO_2, CaO, 2.5 H_2O + 2 CaO, H_2O; that is, rather more than 40% of the cementing principle is simply slaked lime.

Many people ascribe the strength of lime mortars entirely to the absorption of carbonate acid from the air, and overlook the strong bond which lime forms with silica, due to a coating of silicate of lime on each grain of sand.

The large fund of information which Mr. Lesley brings to bear upon the discussion, and the interesting report he gives of the meeting of the German Society, make his paper very valuable, and we are glad to note that the standard test is confirmed in Dr. Pruessing's experiments.

But we disagree sharply with Messrs. Lesley and Booth in considering the addition of sulphate to be essentially bad and undesirable. On the contrary, it seems to us that the use of sulphate within the limits of the German specifications make it an admirable cement for fresh water or air exposures. Cements treated with sulphate possess the peculiarity of setting slowly and hardening quickly. They gain strength rapidly. We have tested cements whose initial set exceeded one hour and a half, but which practically attained maximum tensile strength neat in seven days. And it will generally be found that the treated cements give tests at seven days from 30 to 50% higher than the untreated cements. This is a valuable property, and one well suited for work in rapid progress.

It is true that the addition of sulphate can be overdone, and it is also quite true that for salt water exposures the amount of sulphate present should be limited to quite moderate figures. But these facts are well understood in European practice, and are provided for in specifications, and if our engineers are using cements indiscriminately the fault is theirs and not the manufacturer's.

We have reason to think that in the best practice the total sulphate in treated cements is frequently no higher than in untreated cements. Thus the analyses of two samples of treated cements showed sulphuric acid as follows:

No. 1	0.697%
2	0.886%

Both of these samples are confidently believed to have contained

* See Le Chatelier: "Recherches Experimentales sur la Constitution des Mortiers Hydrauliques."

added sulphate, and both of them are fit for use in sea water. On the other hand, the following analyses represent cements which contained no added sulphate:

No. 3	1.085%	sulphuric acid	(SO_3).
4	1.123%	"	"
5	1.281%	"	"
6	1.161%	"	"
7	1.206%	"	"

Treated cements containing higher percentages than those given in Nos. 1 and 2 are as follows:

No. 8	1.164%	sulphuric acid	(SO_3).
9	1.323%	"	"
10	1.247%	"	"
11	1.340%	"	"
12	2.295%	"	"
13	1.340%	"	"
14	2.108%	"	"

It will thus be observed that the total sulphuric acid in several of the treated cements is about on a par with the percentage in the untreated cements. This would indicate superior kiln work, keeping the so-called " combined " sulphate at low figures.

In conclusion, then, so far as free lime is concerned, the writers are compelled to discard the boiling test. Whether the test has any significance at all is perhaps still open for argument and for investigation.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

735.

(Vol. XXXII.—October, 1894.)

HARPER'S FERRY IMPROVEMENT.

By WILLIAM LEE SISSON, Assoc. M. Am. Soc. C. E.

READ APRIL 18TH, 1894.

At Harper's Ferry, W. Va., 55 miles west of Washington, the three States of Maryland, Virginia and West Virginia come together at the junction of the Potomac and Shenandoah Rivers. Here the Potomac, flowing for some distance southeast, is joined by the Shenandoah, and, breaking through a rugged, picturesque gap in the Blue Ridge, flows eastward nearly at right angles to its former course. The mountains in the vicinity are steep and rugged from their base upwards, the slopes here and there being covered with light growths of timber, and the strata is much distorted and broken. The Potomac at and near this point has an average width of about 1 200 ft., its narrowest part being at its junction with the Shenandoah, where it is only 850 ft. The average depth at extreme low water is about 5 ft., and extreme high water is 36 ft. above this, the rise due to ordinary freshets being from 18 to 20 ft. From Sandy Hook, which is one mile east of Harper's Ferry, the old main line of the Baltimore and Ohio Railroad follows the north bank of the Potomac and the Chesapeake and Ohio Canal

as far as the west side of the mountain gap, where it curves sharply to the left with a 16° curve and crosses the canal and the river on a single-track through bridge of the Bollman type. The north side of the bridge is used for the county road travel. At the east end there is a 16° curve, and at the west end the bridge branches into a Y, the extension of the bridge tangent being used for the Valley Branch and the county road and the other arm of the Y, a curve of 18° being used for the main line. Owing to wooden reinforcing trusses, additional bracing, etc., having been put in to strengthen the original part of the bridge, it is now quite a complicated-looking affair, and its present condition mainly necessitated the change at Harper's Ferry. The old main line then follows the south bank of the Potomac on an iron trestle, reinforced by intermediate wooden bents, for a distance of nearly one-half mile, and, crossing over the old Government canal on a double-track Bollman bridge of 160-ft. span to the foot of the bluffs near Island Park, follows along the West Virginia shore for nearly two miles, at which point it leaves the river. For quite a number of years the Baltimore and Ohio Railroad had been considering the improvement of their line in this vicinity, but it was not until 1892 and after numerous surveys had been made that active measures were taken towards making any change. The main features of the location proposed by Col. James L. Randolph (formerly Chief Engineer) many years ago were adopted, and these, together with a few important changes, constitute the present improvement. In July, 1892, the writer received instructions to make the final location and all plans (except those for superstructure) for the new line between Island Park and Sandy Hook, two miles in all; and also for the new connection to the Valley Branch, one-half mile south from the Ferry, and work was begun one month later.

The change begins at Island Park by replacing 700 ft. of a reverse curve with a tangent to an 8° curve in the old main line at Station 0; thence the line follows with easy alignment and grades along the foot of the bluffs on the West Virginia side to Station 42 + 45.7 where it curves to the left with a 9° 30′ curve to Station 47 + 80 at the west end of the bridge, where it is 8.3 ft. higher than the old main line and 5 ft. above high water; thence crosses the river at an angle of 73° 45′ to its course to Station 56 + 72.82 at the east end of the bridge, where it is 10.9 ft. higher than the old main line. The line then curves to

PLATE XLIV.
TRANS. AM. SOC. CIV. ENGRS.
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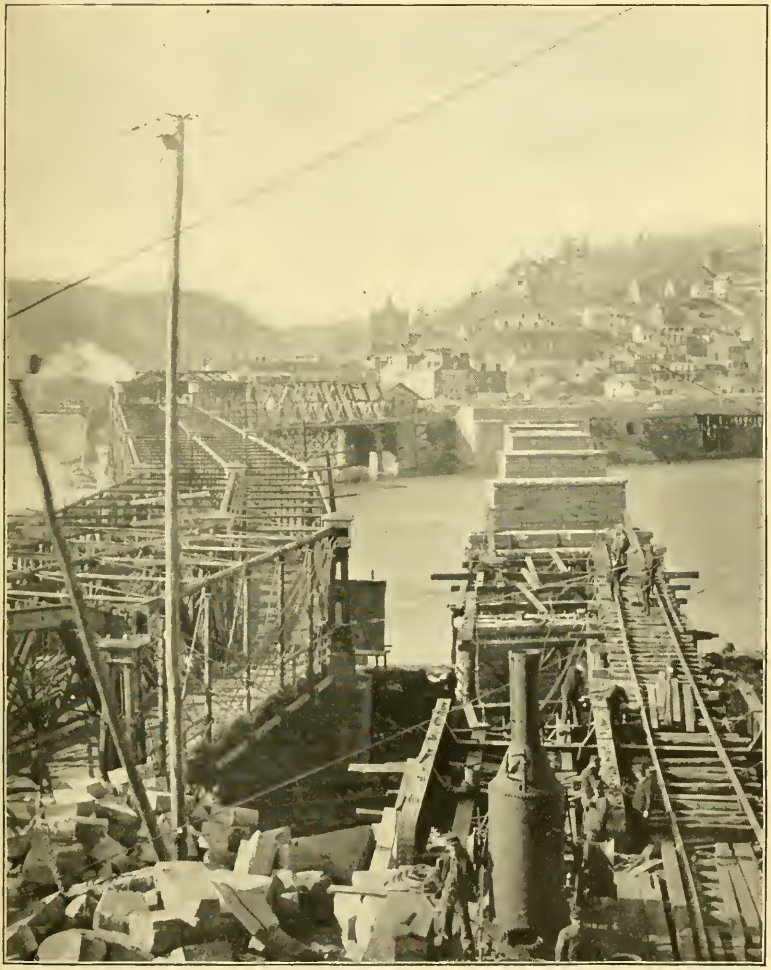
SISSON ON HARPER'S FERRY IMPROVEMENT.



the right with a 7° curve for 100 ft., when it enters an 815-ft. tunnel, the latter 672 ft. of which is straight; from the east end of tunnel the line is an easy compound curve to where it joins the old main line at Sandy Hook.

Owing to the rugged topography of the country and to the position of certain buildings on the line, it was necessary to establish the new line from Station 43 to 68 + 61 by triangulation. The position of bridge tangent being fixed, the first triangulation was for the curve between 42 + 45.66 and 47 + 80, the P. I. and P. T. of which were inaccessible. A base line was first run from Station 43 on tangent to a point on the bridge tangent extended and from angles taken at each end of it, the station of this point (47 + 41) and its distance from the P. I., the P. I. and the station of P. C. were determined. There was no error.

From a point on the bridge tangent, on the north side of the river, and at the foot of the mountain (which is here perpendicular or overhanging for 300 ft. above the river), the second triangulation was made for the distance across the river between Station 47 + 41 and this point, a base being laid out from the centre line 750 ft. along the foot of the mountain. The error in this distance was .02 of 1 ft. In the third triangulation, owing to the position of the point of the 7° curve (Station 56 + 72.82) and the degree having been first determined, it was necessary, not only to locate the tunnel tangent at the assumed angle (which had been found to be approximately 17°), but also at the calculated distance from the P. C. From this data the tangent of curve was calculated, and together with distance across river to Station 47 + 41, as found by the second triangulation, was taken as a base line, which, in conjunction with the intersection angle and an observed angle at Station 47 + 41, was used to determine a second base line and an angle by means of which to prolong the tunnel tangent eastward. The error of alignment where the lines met in the headings of the tunnel was ½ in., and the intersection afterwards found to be exactly 17°.

The fourth triangulation was made necessary by the steep slopes and roughness of the ground over the tunnel, which did not allow of accurate measurements. The tangent distance of the 7° curve (as assumed in the third triangulation) was taken as a base, from which angles and distances were carefully measured around the foot of the mountain to a point on the center line on the east side. The distance

measured through the tunnel afterwards was 0.2 of a foot less than that calculated.

In the fifth triangulation, it was desired to obtain the angle of intersection which the tangent to the reverse curve of the valley connection made with the bridge tangent, the point of intersection being in the river. This was done by taking from each end of a base line, between Station 47 + 41 and a point on the Valley Branch, angles to the bridge tangent and to the Valley Branch. By the sixth triangulation, the distance from the point of intersection of the bridge tangent and the Valley connection to an arbitrary point on the latter was next found, and from this point stations on the Valley connection were determined by direct measurements. There was no error in either of these last two triangulations. It will be observed that in this work all of the triangulations were made assuming the first two to be correct, and that the accuracy of each one was dependent upon that of a preceding one.

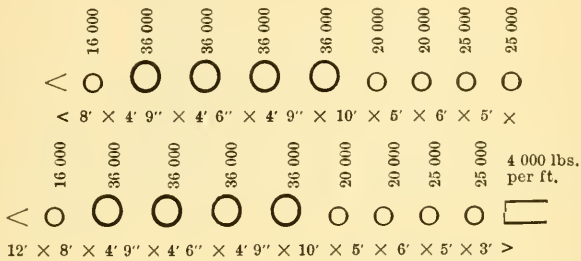
The work of construction involved in making the changes for the Harper's Ferry improvement was as follows: From Island Park one-half mile east along the bluffs on the West Virginia side of the river there were 50 000 cu. yds of solid rock cutting, the cuts in some places being 80 ft. high. The rock, limestone and mica schist, when broken up and hauled an average of 2 600 ft. to embankment, made nearly 90 000 cu. yds., an increase of 80 per cent.

The river bridge consists of four deck spans of 85 ft. 6 ins., three through spans of 140 ft., one deck span of 100 ft., and one half-through span of 34 ft. 6 ins., making a total length of 896 ft. 6 ins. The piers of the bridge, eight in number, are set at an angle of 73° 45′ with the center line, and are 6 x 37 ft. on top, and from 34 to 36 ft. high above neat line, and are located directly opposite, and on a line with, the piers of the old bridge, so as to obstruct the water-way as little as possible, and are on a grade of 0.3%, the coping of them being level. They are built of Gettysburg granite and are founded on solid rock. The rock, being generally uneven and full of crevices, was prepared by cutting away the loose or decayed portions of it and then leveling with concrete, mixed in the proportion of 1 part of Portland cement, 2 parts of coarse sharp river sand, and 5 parts of broken stone.

While putting in the foundations the depth of water was about 6 ft. In several cases the Wakefield sheet piling was used for the coffer-dams with good results, both as regards cost and efficiency.

CANAL
POTOMAC
MARYLAND
WEST VIRGINIA
SHENANDOAH
VIRGINIA
RIVER
FERRY
RIDGE STREET
YORK STREET
POTOMAC STREET
HIGH STREET
SHENANDOAH STREET
HAMILTON STREET
HARPERS
IMPROVEMENT
COUNTY ROAD
C. & O. CANAL
RACE
FERRY

The superstructure is of mild steel, except the eye-bars, pins and rollers, which are of medium steel ; and is designed for a moving load on each track of two 125-ton consolidation engines, coupled, followed by a train load of 4 000 lbs. per linear foot. Weights distributed as follows:



The through spans are single intersection Pratt trusses, 137 ft. *c* to *c* of end pins, 30 ft. high, and 28 ft. 4 ins. *c* to *c* of trusses. The deck spans, of 85 ft. 6 ins., are plate girders, three to each span, 85 ft. out to out of girders, 9 ft. center to center of girders, and 7 ft. 10 ins. deep. The 100-ft. deck span consists of three plate girders 7 ft. 10 ins. deep ; 9 ft. center to center of girders, and 99 ft. 8 ins. out to out. All of the spans are for double track, except the two at the west end of the bridge, which are built for two main line tracks, and the one of the Valley Branch, which here form a Y, the space between the two branches being spanned by plate girders and floored over for a platform.

SUBSTRUCTURE OF BRIDGE.

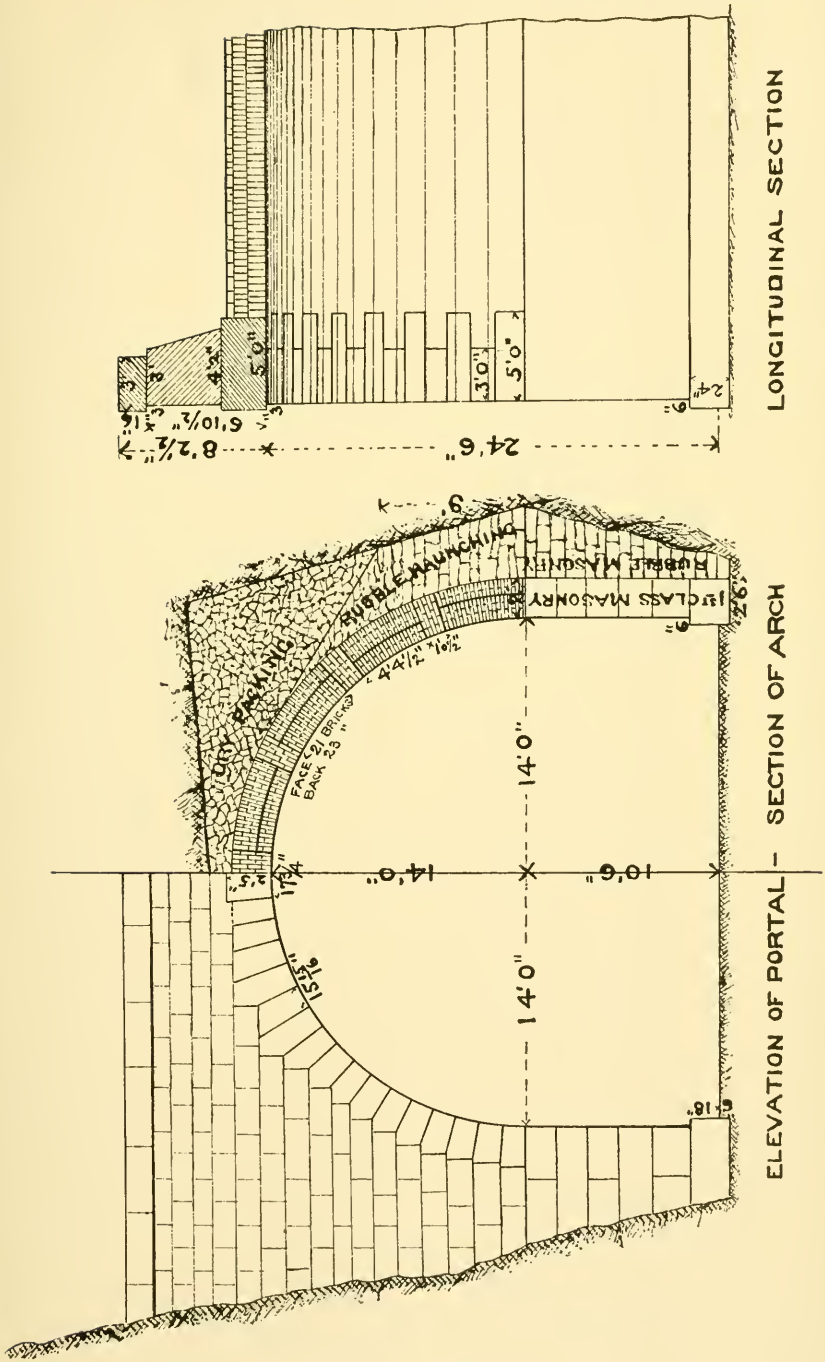
Excavation of foundation, at 75 cents.		MASONRY.									
		First Class, at $10.		Rubble, at $5.		Concrete, at $6.60.		Cement at 85 cents.		Total.	
Cubic yards.	Cost.	Cubic yards.	Cost.	Cubic yards.	Cost.	Cubic yards.	Cost.	Barrels.	Cost.	Cubic yards.	Cost.
2 406	$1 804 50	3 552	$35 520	1 404	$7 020	340	$2 108	4 068	$3 457 80	5 296	$49 910 30

Plate XLVIII is a view of the old and new bridges.

A double-track tunnel 812 ft. long begins 103 ft. from the east end of the bridge and extends through the mountain spur at this point.

The size is 28 ft. wide at the springing line 10 ft. 6 ins. above subgrade and semi-circular arch of 14 ft. radius. The rocks are mica schist with quartz seams, passing into micaceous gneiss, and dipping to the eastward. The strata in places is much contorted and broken. The west portal is at the foot of a cliff 250 ft. high, the approach cut here being 70 ft., and at the end of bridge 40 ft. At the east end the portal slope of the cut is 112 ft. on the upper and 40 ft. on the lower side. The tunnel was driven with Ingersoll-Sergeant drills worked by compressed air supplied by a compressor at the east end of the tunnel, pipes being laid around the foot ef the mountain to supply the west end drills. The headings were 8 x 25 ft., the full top section of the tunnel, and were kept only 15 ft. in advance of the bench, as no timbering was necessary. The rate of progress for heading and bench in the east end was 18 ft. or 401 cu. yds. per week, and in the west end 19 ft., or 423 cu. yds.

From the position of the strata and the presence of large cross seams at both ends of the tunnel it was considered necessary to line 80 ft. of the west, and 45 of the east, end, both portals being in the open cuts about 10 ft. from the ends of the tunnel. The arched portion was of the same size in the clear as the remainder, the arch being built of five rings of bricks, with bench walls of first-class masonry 2 ft. thick, backed with rubble masonry carried up to a point 9 ft. above the springing line, the remainder of packing being stone placed by hand. As it was necessary to lay track through the tunnel, to deliver bridge material at the west end, before the arching was completed, the plan of centers as shown was used. In estimating the actual amount of tunnel excavation, and finding points within the prescribed section, a simple and accurate machine was used, as shown (Plate XLVII). Its weight was about 90 lbs., and cost $4. It was easily moved around by two men. Upon the side pieces, inclined at 45°, were marked degrees from 0 to 90, and upon the lever or pointer, feet and tenths were numbered from the top downward. In cross-sectioning, the foot of the machine was first set at center and grade, and the vertical pieces then plumbed, bringing the center pin at center on the springing line; the pointer was then run out to any desired place, and the distance on the pointer to the center pin and also the angle on the inclined piece noted. In this way the measurements and angles taken above the springing line formed a series of triangles, which were calculated by


LONGITUDINAL SECTION
24'6"
8'2½"
6'10½"
5'0"
4'2"
3'0"
2'4"
SECTION OF ARCH
1st CLASS MASONRY
RUBBLE MASONRY
RUBBLE RAUNCHING
DRY PACKING
FACE 21 BRICKS
BACK 23 "
4'4½"
10½"
14'0"
10'6"
9"
ELEVATION OF PORTAL
15'5"
17¾"
2'5"
6'18"

Tunnel Excavation.

	Solid Rock, at 75 Cents.		Tunnel Excavation.								Crushing Ballast at 45 Cents per Cubic Yard.		Total Amount.	
			Per linear foot.				Total, at $2 10.		Overhaul at 1 cent.					
	Cu. yds.	Cost.	Original section. Cu. yds.	Additional section. Cu. yds.	Total section. Cu. yds.	Cost.	Cu. yds.	Cost.	Cu. yds.	Cost.	Cu. yds.	Cost.	Cu. yds.	Cost.
West approach...	7 423	$5 567 25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	7 423	$5 567 25
Tunnel.....	.....	.....	22.29	2.03	24.32	$51 07	19 868	$41 722 80	132 263	$1 322 63	472	$4 712 40	19 868	47 757 83
East approach....	15 920	11 940 00	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	15 920	11 940 00
Total amounts.....													43 211	$65 265 08

Tunnel Masonry.

	Lining.				Packing.						Cement.		Cost.		Portals.	
	First-class masonry, at $9.		Arching, at $9 50.		Rubble, at $5.		Haunching, at $2 50.		Dry packing, at $1 50.							
	Cu. yds.	Cost.	Cu. yds.	Cost.	Cu. yds.	Cost.	Cu. yds.	Cost.	Cu. yds.	Cost.	Barrels.	Cost, at 85 cents.	Per lineal foot.	Total.	Cu. yds.	Cost.
West end.....	127	$1 143	270	$2 565 00	101	$505	183	$457 50	967	$1 450 50	650	$552 50	$83 42	$6 673 50	82	$820
East end.....	68	612	145	1 377 50	55	275	105	262 50	248	372 00	355	301 75	71 13	3 200 75	82	820
Total amounts...	195	$1 755	415	$3 942 50	156	$780	288	$720 00	1 215	$1 822 50	1 005	$854 25		$9 874 25	164	$1 640

Total cost of tunnel..... $76 779 33

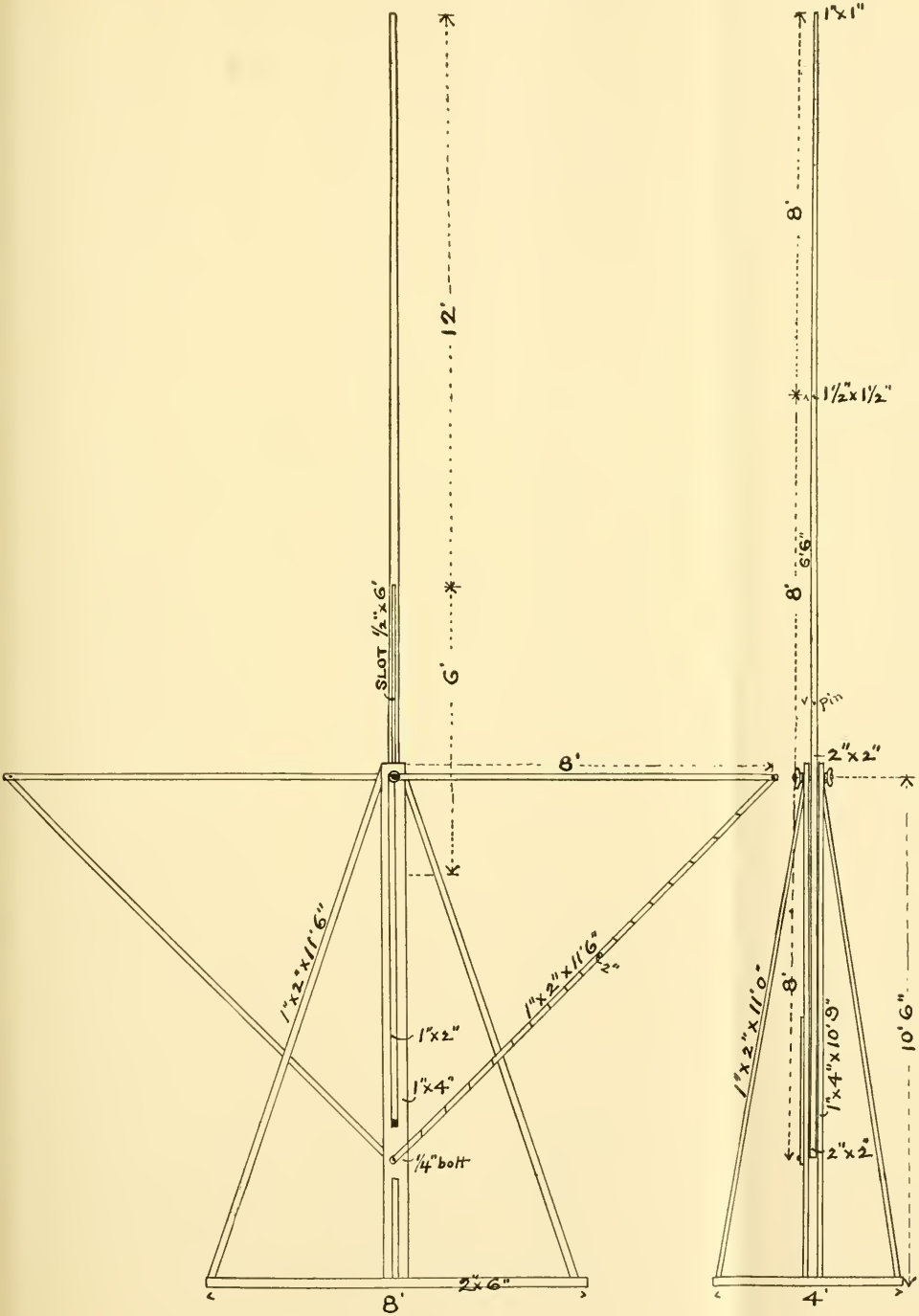
the rule, area = product of the two sides and sine of included angle divided by two.

In using the machine merely for finding points within the prescribed section, the inclined and horizontal side pieces were removed and only the pointer used. It will be readily seen that the relative proportions of the different parts insured very accurate results. The disposition of the tunnel material was made as follows: 5 800 cu. yds. was crushed into 10 472 cu. yds. of ballast by a Gates' Crusher No. 4 at the east end, and by a Blake at the west end; then loaded into cars and shipped to different parts of the road. The remainder, 16 482 cu. yds., was used for the embankment east of the tunnel and for raising the county road and the main-line tracks between Sandy Hook and the tunnel.

The county road which originally, from Sandy Hook to the east end of Harper's Ferry bridge, ran parallel to the old main line, and north of it, on the same level, was raised 36 ft. at the east end of the tunnel, to make an overhead crossing of the new line (as shown by Plate XLVIII), and also thrown up against the mountain side, so as to get a 4% grade from this point (Station 68) down to Station 77, where it runs into the old road; at the same time, in order to make the work as light as possible, it was so located that the foot of the slopes of its embankment came just 15 ft. from the new center line at the new grade. The west approach to this crossing, also on a 4% grade, was made by gradually raising the old road between the old main line and the side of the mountain 2 ft. at a time, to keep travel going until the proper height was attained, when additional width, necessary to make a 20-ft. roadway, was obtained by cutting into the steep slope of the mountain, as shown by Plate XLVIII. At the west end of the tunnel the county road was depressed 4 ft. to make an undergrade crossing of the new line, for which a clearance of 12 ft. was required.

CHANGE OF NEW COUNTY ROAD.

Description of Work.			Quantities.	Cost.
Excavation of solid rock	at $	75	5 700 cu. yds.	$4 275 00
Rubble masonry	"	5 00	433 "	2 165 00
Dry rubble wall, for fence	"	95	560 "	532 00
Cement	barrels, "	85	400 bbls.	340 00
Wooden Howe Truss Bridge 50-ft. span (in clear), ft. B. M.	"	47 00	12 480 ft. B. M.	585 15
Pounds iron	"	03½	623 lbs.	21 80
Total cost of change				$7 918 95


12'
SLOT 1/2"x6'
6'
8'
1"x2"x11'6"
1"x2"x11'6"
2"
1"x2"
1"x4"
1/4" bolt
2"x6"
8'
1"x1"
8'
1 1/2"x1 1/2"
8'
6'6"
Pin
2"x2"
8'
1"x2"x11'0"
1"x4"x10'9"
2"x2"
10'6"
4'

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From Station 73 + 50 to 101, the alignment and grade of the old main line had to be changed to properly connect with the new line, and, while making the change, still maintain the travel. This was done by first laying a third track from Sandy Hook west to Station 77, parallel to and south of the main-line tracks. Between these points the former east-bound track was used as west-bound, and the third track used as east-bound track, after having been connected with the west and east-bound tracks of the main line west of this point (Station 77). The former west-bound track, having been cut loose, was then raised to its full height to conform to the new grade, which was 7 ft. higher at Station 73 + 50 than the old one. The present west-bound track was also, at the same time, gradually raised 9 ins. at a time to the final height; this additional height was run off by means of a heavy grade westward, which was in favor of trains using that track. When the remainder of the work was completed, the road was operated by connecting and distorting both tracks until the new embankment between Station 72 + 50 and 78 was widened out to its full width, which here occupied both of the old tracks; the position of both tracks was then gradually shifted until it finally corresponded to the new alignment. as shown by Plate XLVIII. Between Station 74 + 50 and 76 + 75 a new retaining wall was built along the canal, to catch the extension of the slopes, caused by the additional height of the embankment for the new main line.

The force engaged in raising track was, 1 foreman, 10 men, for 120 days, which, with foreman at $50 per month, and men at $1.15 per day, cost $1 617 69. The amount of material used to make this raise was about 5 000 cu. yds., making the cost per cubic yard about 32 cents. The work was necessarily slow and expensive, as the track had to be kept in good line and surface during the raising of it. The above cost does not include the widening of the embankment between Station 72 + 50 and 78, which, as stated, was done gradually afterwards.

During the raising of the main line, the old county road was also gradually filled, and the travel maintained over it, and the west approach to the overhead crossing at Station 68, until the east approach and crossing were completed when the travel was turned over all of the new road previous to the completion of the change in the main line.

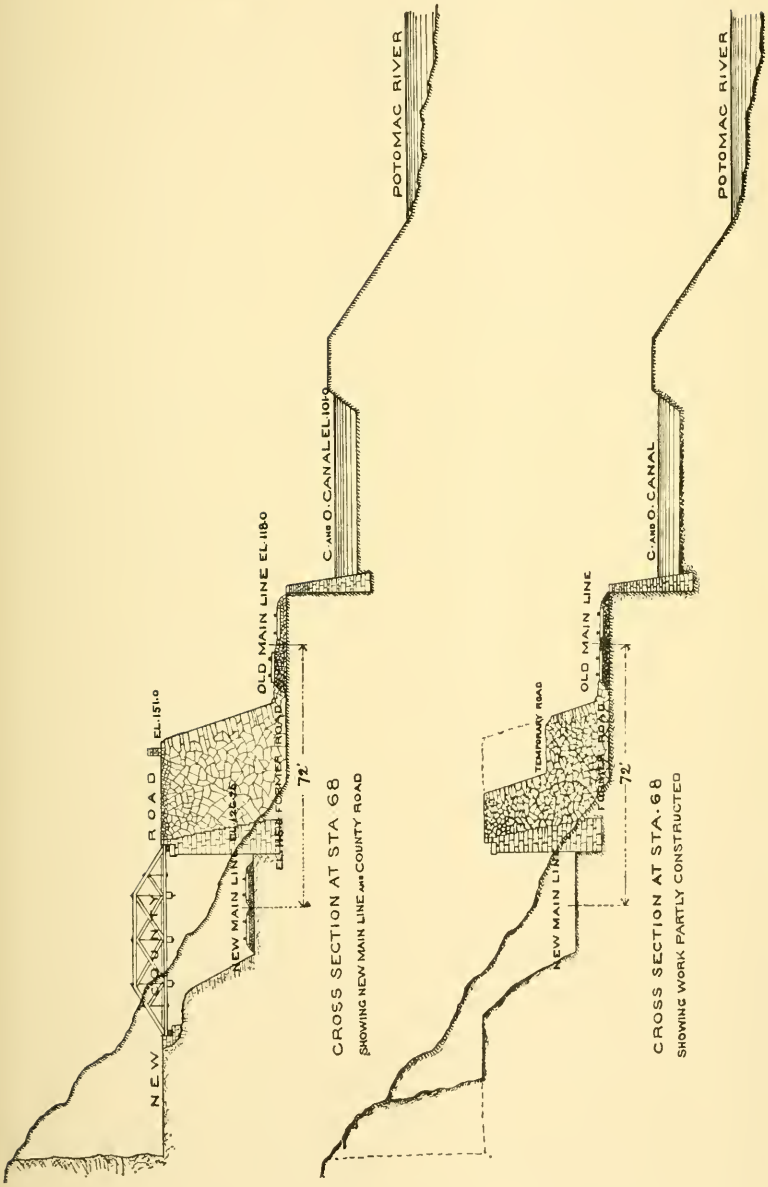
On the West Virginia side of the river at the junction of the new main line and the Valley connection, the width between the river and

Shenandoah Street was insufficient for suitable station grounds, and to obtain the proper width at this point, the street was changed as shown, crossing the new valley connection under grade. The high embankments both on the new main line and connection made necessary the construction of an arch culvert (with 5-ft. bench walls and 5-ft. radius of arch) leading from Shenandoah Street to the river, 186 ft. distant, to provide proper drainage for the lower part of the town in case of an overflow from the Shenandoah River, which at such a time floods this street further south and then flows towards the station. The relative heights of the street and old main line were such, that, to build the arch under the tracks without interfering with trains, it was necessary to make the grade of culvert 1 ft. in 100 ft., which allowed the arch to clear the bottom of the track stringers 6 ins. One of the floor beams, however, had to be removed, as shown on the plan, and temporary timbers put in, resting upon posts placed on each side of the arch, these timbers in turn supporting stringers parallel and close to the regular iron track stringers which alternately broke joint. As the arch was built up, the stringers were blocked up above it and such posts as were in the way removed. The cost, including timber, was $75. The space between the street and the river had in the course of many years been filled with earth from 15 to 20 ft. above the solid rock. At the point where the culvert goes through the old retaining wall, a bed of concrete, 3 ft. thick, 22 ft. wide, and extending back 17 ft. from the old wall and 5 ft. into it, was used; and upon this 3 ft. 6 ins. of rubble the full width of the culvert was laid; the remainder of the culvert was built with ordinary side walls and paving between. The river end of the culvert was built flush with the face of the old retaining wall, which is at an angle of 66° with the axis of the culvert, and on a batter of 3½ ins. to 1 ft.

The cost is as follows:

Rubble	690 cu. yds., at $5 00	$3 450 00
Paving	80 " " " 2 00	160 00
Concrete	75.5 " " " 4 85	366 17
Brick	142 " " " 9 00	1 278 00
Second-class masonry	58 " " " 8 00	464 00
Cement	800 bbls., " 0 85	680 00
Total cost of culvert		$6,398 17
Cost per linear foot		$34 40

PLATE XLVIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 735.
SISSON ON HARPER'S FERRY IMPROVEMENT.



The new Valley connection from Shenandoah Street, 330 ft. south, is embankment, along part of which a retaining wall was necessary, to confine the slopes within the right-of-way limits, the wall being built straight along the property line, and stepped every 10 ft. 6 ins., so as to properly retain the slopes of embankment, the center line of which is a 19° curve.

From the end of this embankment, south 1 150 ft., is a double-track trestle of an average height of 18 ft. above pedestals, or about 7 ft. higher than the old trestle-work. At the north end of the trestle there is a 3° 54′ curve for 190 ft., compounding then into a 7° 10′ for 180 ft., and then a 2° for 100 ft., the remainder being tangent. In some places the old trestle was 18 ins. off of the new alignment, the change being made as the new trestle was built. In building this a temporary single-track trestle was built from Station 1 + 40 to 0 of the Valley connection, and from there on one-half of the permanent trestle was built and used for main track until the other half was raised (the temporary one being then filled in). The new bents were so located that none of the old ones were disturbed until both tracks were in operation. The cost of the trestle was as follows:

Excavation of foundation for pedestals, 350 cu. yds., at 18 cents	$63 00
Pedestals of rubble masonry, 248 cu. yds., at $5	1 240 00
Second-class (caps) masonry, 120 cu. yds., at $8	960 00
Lumber, 468 600 ft. B. M., at $31 75	14 878 05
Iron, 29 910 lbs. (included in price of lumber).	
Total cost	$17 141 05

Cost per linear foot, $14 90.

Iron per M of lumber, 63¾ lbs.

The 60-ft. half-through span at the south end of the trestle was raised by removing (between trains) some of the blocking from under the new trestle (which had been first carried across the bridge on blocking) and jacking the whole span a corresponding distance, until the final height was attained.

From this end of the trestle, south 1 800 ft., the tracks of the Valley Branch were raised, one at a time, to conform to the new grade, which at the trestle was 5 ft. 9½ ins. higher, and 1 800 ft. further south ran

into the old grade. The force engaged in raising the first track was 1 foreman, 10 men, for 45 days, which, at $50 per month for foreman, and $1.15 for men per day, cost $604. The amount of stone required to make this raise was 1 935 cu. yds., making the cost per cubic yard about 31 cents.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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736.

(Vol. XXXII.—October, 1894.)

THE MYRTLE AVENUE IMPROVEMENT ON THE BROOKLYN ELEVATED RAILROAD.

By O. F. NICHOLS, M. Am. Soc. C. E.

READ OCTOBER 3D, 1894.

WITH DISCUSSION.

While heavy grades are quite as objectionable on elevated as on surface railways, the use of double stations, as distinguished from island or intertrack stations, increases operating expenses more rapidly than heavy grades, and introduces a railway problem not often found on surface lines. These double stations are frequently convenient, sometimes necessary, but always expensive. This last-named feature is occasionally overlooked. Few realize, for example, that the Manhattan Railway Company could pay a dividend nearly 1% larger on its stock, if it could use island stations over its whole line.

The radical change of conditions already existing is a serious matter, and it is often difficult to determine the amount of money, time and inconvenience which may be wisely expended to effect a change. It is the purpose of this paper to describe a single attempt to improve

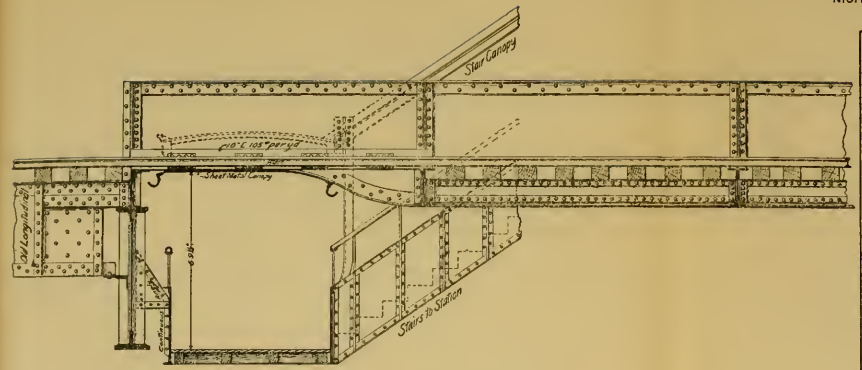
grade and stations on the Brooklyn Elevated Railroad, to enumerate the difficulties encountered, to describe the methods of overcoming them, and to show that this particular change was a profitable one to make.

The conditions as to grade and station location were somewhat peculiar on the Myrtle Avenue line, especially between Bridge Street and Grand Avenue. The grade on the surface of the street reached 4% for some distance east of Raymond Street; this necessitated a heavy grade in the elevated tracks, if the Hudson Avenue and Myrtle Avenue lines were to meet at a common low elevation.

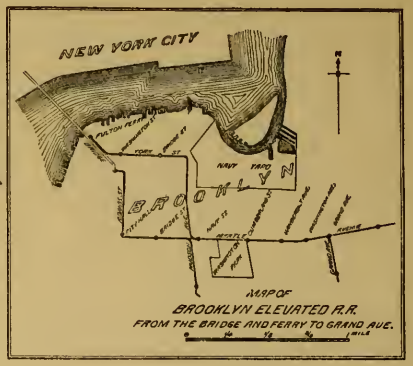
All the other stations on this line were island stations, excepting those at City Hall, Grand, Washington and Vanderbilt avenues. The Grand Avenue station formed a transfer for passengers between the Myrtle Avenue and Lexington Avenue lines through a system of overhead foot bridges. To change the two next adjacent stations to island stations would save much money in operation, change the transfer from Grand to Washington Avenue and make it possible to simplify and economize still further at Grand Avenue at some later time (see map, Plate XLIX).

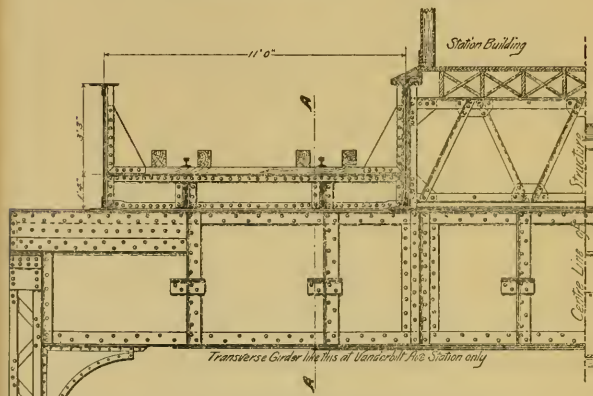
Through accidental conditions the Washington Avenue station had been built after the road was completed. It was placed on a grade of 1.4%, and, with the Vanderbilt Avenue station, was permanently fixed in position by agreement. Engines frequently stalled in starting heavy trains from the station on this grade, and it seemed necessary to change it if possible. The long stretch (1 700 ft.) of 2.06% grade between Navy Street and Carlton Avenue had caused much trouble and anxiety. More accidents to engines had occurred on this grade than on any other equivalent length of the road.

A careful study of the problem, in 1889, led to the proposition to change the two stations and the steep grade, making the grade line follow the dotted line, as shown on profile (Plate L), and cross Hudson Avenue at a high level; this proposition seemed impracticable on many accounts at the time, and the entire project was abandoned to be taken up again early in 1893. The travel then having increased so as to crowd the terminal station at the Bridge, it was proposed to run five car trains over Myrtle Avenue, and to make it easier to do this it was decided to cut the heavy grade in two, lengthways, lessening and lengthening the upper part of it. The steep grade would then be

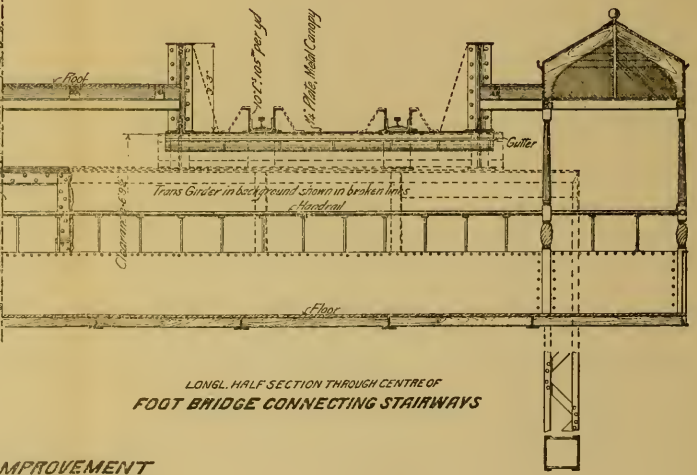


SECTION A-A





TRANSVERSE HALF SECTION THROUGH
STATION BUILDING, FOOT BRIDGE REMOVED



LONGL. HALF SECTION THROUGH CENTRE OF
FOOT BRIDGE CONNECTING STAIRWAYS

MYRTLE AVE. IMPROVEMENT
DETAILS OF THROUGH SPANS

about the same length as two or three other pieces of the same gradient on other branches of the road, and it would then be possible to place a station at Cumberland Street.

Studies were made for changing the grade below Carlton Avenue and above Washington Avenue, for changing the two stations to island stations, and for providing a new station at Cumberland Street. The steady increase of travel in 1892, and well into 1893, fell off, owing to the financial depression of the early summer and the advent of the use of electricity on the surface lines. Short riders were more attracted by the newer method of travel, and it was decided to complete the iron work only for the new station, leaving the balance of the work on this Cumberland Street station to be finished at some later day.

The problem was so complicated that it was difficult to make a very close estimate of the cost of the work. In the preliminary report $40 000 was named as the probable cost of the entire improvement.

The lowering of the grade between bents 68 and 92 was regarded as the most serious portion of the work, since it must be done without interference with travel, and on account of the importance of doing it in such manner and with such appliances as should command the confidence of the public without attracting too much attention. Any failure in this respect might easily double the cost of the work from loss of passengers alone.

Plans and estimates for doing the work were sought from experienced bridge erectors; nothing, however, resulted in the way of plans more satisfactory than those already prepared, and no one would agree to undertake the execution of the work on terms other than a percentage on its cost, which seemed too indefinite for acceptance. It was, therefore, decided to purchase the tools and materials and do the work by day labor under the supervision of the roadmaster, who had had much experience in changes of elevated railway structures, both in New York and Brooklyn.

The earlier plans proposed to cut a section out of each column a little above its base, splicing the two parts of the column together with plates riveted on the sides; this avoided the awkward cutting of columns, about 20 in number, on which the "drop end" girders extended down the side of the column more than 2 ft.; it also retained the rigid connections between columns and girders, which it then seemed wise to rely upon, in part at least, as a safeguard against

any overturning tendency. It was desirable to do the work during the months of May and June, when the weather would be most favorable, and the travel lighter than in the early spring months, and it was important to finish the changes in the main structure and track system before the cables and wires of the surface trolley road underneath were attached to the structure and actually in use, or, say, before the middle of August.

Considerable time was lost in attempting to secure a cold saw for cutting the columns. Two of the saw-makers took little, if any, interest in the problem; the makers of the Higley saw were much interested and designed a tool which promised to satify the conditions fully. The saw was designed to work by hand or by electric power on an iron frame clamped to the side of the column; the saw blade, 12 ins. in diameter, was arranged to pass through the column, cutting one channel completely off in transit. It was estimated that the saw would make each cut in less than half an hour. The weight of the machine was about 600 lbs., and its cost $500. The delay necessary to make the saw and the demonstration by actual test that all the channels actually cut could be cut off by hand for about the price of the saw, led finally to the abandonment of machine cutting.

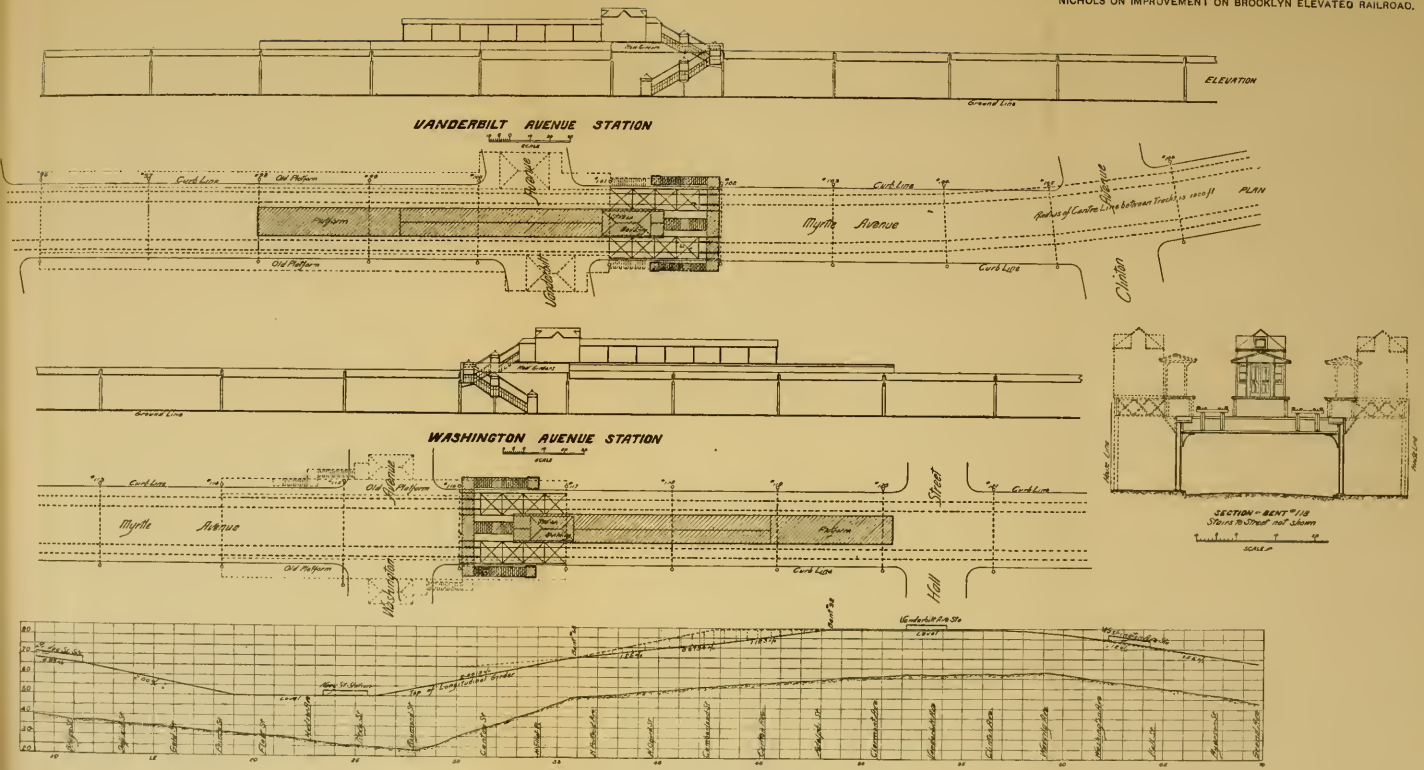
The saw was first proposed when the cutting at the base was considered. Only one-fourth of the cutting was required at top of columns, while the difficulties and delays in handling a heavy machine would have been increased by raising it from the ground.

The plan of cutting at the top of columns was developed partly from the fact that the work of cutting and splicing the columns would be done at a disadvantage, unless a system of blocking and lowering could be devised which would leave a large free space about the base of columns.

The street roadway must be kept clear, so as to leave space for vehicles between the blocking and the surface car tracks. This became more important when the surface road commenced the relaying of its tracks and the repavement of the street about them almost simultaneously with the commencement of the work on the structure.

The columns were firmly fixed by rust joint into heavy cast-iron bases about 3 ft. square, and these were bolted to brick masonry piers. It was finally decided to take advantage of the columns themselves to steady the lowering apparatus, and to cut the columns off at the top.

PLATE L.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 736.
NICHOLS ON IMPROVEMENT ON BROOKLYN ELEVATED RAILROAD.



The yellow pine timber for lowering was ordered directly from the south from economical motives and to secure good sound heart timber, to resist the heavy unit stresses liable to come upon it. All of the vertical sticks were suspended from the transverse girders; this avoided all handling of these timbers during the progress of the work. The larger vertical timbers were secured to the girders by built T-irons, bolted to the sticks and to the girders to aid in preventing tilting of the girders. Two channel irons, held together by four bolts, formed clamps placed near top and bottom of columns, to steady the timbers; the middle bolts served as separators, and the end bolts as guides. A space was left between the back of column and the corresponding bolt, to allow the column to spring out $\frac{5}{8}$ in. at the top when the girder was lowered into the back channel of the column; this space was filled by wooden wedges at other times.

Two 60-ton hydraulic jacks were used, one under each of the smaller sticks at each end of the girder. When the larger timbers were placed in position they were left 12 ins. short of reaching the main blocking. This space was filled by three carefully dressed blocks 4 ins. thick, 14 ins. wide and 3 ft. long, bolted through edgeways, to prevent splitting.

The brackets were cut out between columns and girders, the blocking and vertical timbers were carefully placed and lock wedges driven under the large timbers, to give a firm and uniform support. The side plates and angles forming caps of the columns were then removed and placed in correct position for new caps, the rivet holes having been previously drilled. The horizontal seat plates were cut out to fit the back channel which was to be left intact; the edges of the vertical angles at ends of girders were also cut, to make sure of their entering the channel freely.

When the sides of the column cap were secured in new position the inside channel of the column was cut off with a heavy diamond-point tool held by one man while another struck it with a heavy hammer; the diamond-point was made of $1\frac{1}{4}$-in. octagon steel about 2 ft. long. Two men would frequently cut a channel off in two hours; the surface of the cut was afterwards dressed up with hand chisel and hammer.

The men worked at top of columns on a platform about 6 ft. square, formed of loose planks, enclosing the columns resting on two joists

suspended by ropes, one from the track timbers and the other from a cross-tie clamped to the girder over the column. As soon as the new column cap was completed by adding its top plate, blocks 6 x 6 x 18 ins. were piled on it in pairs and wedged under the end of girder, to give additional support.

The cutting of the columns was started at the summit of the grade where it amounted to 5 ft. 7¼ ins. When the columns of three bents had been cut, the girders of these bents were at once lowered 4 ins.; the columns were sprung out by slacking the wedges at the back clamp bolt and driving other wedges between the column and the heavy timber; the girders at once entered the channels, which from this on formed guides to steady and keep them in place. The cutting was extended until the girders at the summit could be lowered 12 ins. All the cutting was then completed and the general lowering began, commencing at the easterly or upper end, care being taken not to produce grades exceeding 0.6% and to gradually reduce the heavy grade on the westerly end to its new limits.

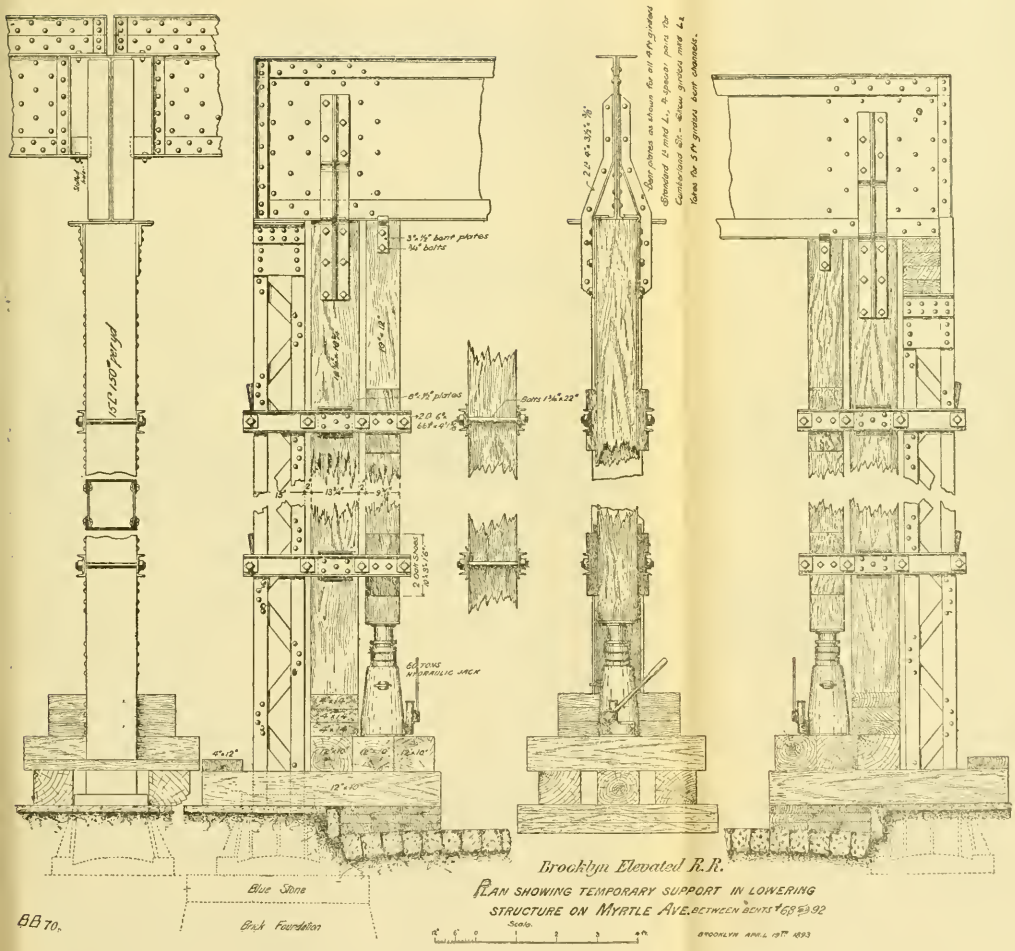
The lowering was done by two gangs of six men each, one on each side of the street at each of the columns; the superintendent with one gang, and the assistant with the other. Two men handled the jack, two the blocking, and the other two adjusted the clamps, which were never allowed to get too slack or drop out of position.

The jacks had 12 ins. lift, and had let-off cocks by which the lowering could be checked at any point by the slight movement of a key in the hand of the foreman of the jack. They weighed 300 lbs. each, and were easily carried from column to column by four men, using a hand spike put through rope slings in the handles.

In lowering, the jacks were set up to relieve the 4-in. block; this was then backed out, followed by a block 1 in. thinner, and this in turn backed out, followed by a thinner one in the same manner. In case of accident to the jack the vertical timber could not, therefore, drop more than 1 in.

When each girder had been lowered the first 12 ins., it became necessary, if it was to go lower, to saw off the heavy vertical timbers. The girders were then blocked directly on the iron column, the jacks slacked and the timber sawed off 16 ins. A lowering of 4 ins. again brought the blocking to the standard of 12 ins.

When a 4-in. drop was carried over the entire line, two girders, one


Bolted 10" x 10"
3"x½" bent plates
¾" bolts
8"x½" plates
Bolts 1¼"x22"
60 tons hydraulic jack
Blue Stone
Brick Foundation
Brooklyn Elevated R.R.
Plan showing temporary support in lowering structure on Myrtle Ave. between Bents 68 & 92
Scale
Brooklyn April 19th 1893

BB 70.

at each end, would generally reach their final bearing at each trip. Such a drop was once carried over the line in three and a half hours, and a second drop completed the same day, or the structure lowered 8 ins. in one day, averaging about 8 minutes to each column.

The first blocking was placed on June 1st, 1893.

The first column was cut off on June 7th, 1893.

The first lowering was done on June 13th, 1893.

The cutting was completed on June 22d, 1893.

The lowering was completed on July 1st, 1893.

The greatest weight obtainable on any column from structure and trains was 156 000 lbs.

The amount of cutting at the several bents was as follows :

Bent No.	69,	0′	5″	Bent No.	81,	5′	$7\frac{1}{4}$″
"	70,	0′	$9\frac{13}{16}$″	"	82,	5′	$4\frac{7}{8}$″
"	71,	1′	$3\frac{1}{16}$″	"	83,	4′	$11\frac{7}{16}$″
"	72,	1′	$7\frac{7}{16}$″	"	84,	4′	$5\frac{3}{8}$″
"	73,	1′	$11\frac{7}{8}$″	"	85,	3′	$11\frac{9}{16}$′
"	74,	2′	$4\frac{5}{16}$″	"	86,	3′	$3\frac{7}{8}$″
"	75,	2′	$9\frac{15}{16}$″	"	87,	2′	$7\frac{1}{4}$″
"	76,	3′	$3\frac{5}{8}$″	"	88,	1′	$11\frac{7}{16}$″
"	77,	3′	$8\frac{3}{4}$″	"	89,	1′	$3\frac{3}{4}$″
"	78,	4′	$4\frac{9}{16}$″	"	90,	0′	$8\frac{1}{8}$″
"	79,	5′	$0\frac{7}{16}$″	"	91,	0′	3″
"	80,	5′	$5\frac{7}{16}$″				

While it was practicable to do the entire work with trains in motion at the regular speed of 15 to 20 miles per hour, this was not necessary, and no lowering was actually done under a moving train. General instructions had been given that the work should be so conducted as to give the appearance of absolute safety as well as to secure it.

Green flags were displayed a few hundred feet each side of the critical points, all trains were run over the entire work at reduced speed, and a flagman was on duty to halt trains, though this was seldom necessary. The hours of most frequent trains were utilized in preparations, and the lowering generally took place between 10 A. M. and 5 P. M., when the travel was lightest. Even at this time trains crossed a given girder at average intervals of about one and a half minutes.

The actual shortening in the length of the grade due to lowering was calculated to be about three-fourths of an inch. It was supposed

that the single bolts connecting the longitudinal girders to the transverse girders might be sheared off by compression. This did not occur, however; the shortening seemed to distribute itself uniformly, and to be taken up by the slotted holes at one end of each span. The rails had been quite tight on the grade and closed together at the summit, with a tendency to spread; about 2 ins. was cut out at the joints at this point, which, with the shortening, expansion and movement of the rails under traffic, was quickly taken up.

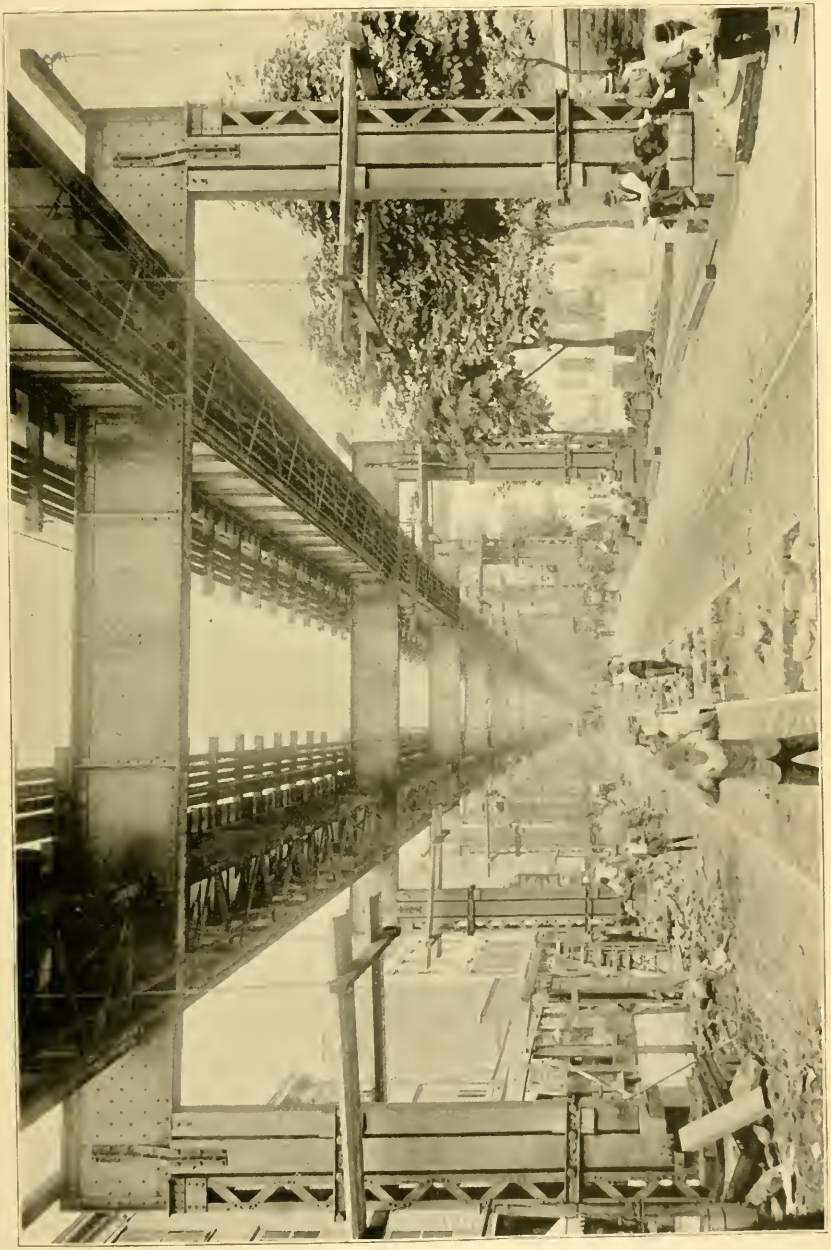
When the entire lowering was completed the girders were securely riveted to the long channel of columns, left in place, giving a rigid connection of girders to columns. When this channel extended above the top of girder, as it did in several cases at the old summit, the excess in length was cut off.

The entire force of men employed in the work of lowering and preparations therefor consisted of 30 men, classified as follows:

Carpenters	2	Riveters (four gangs)	8
Drillers	6	Trackmen, Helpers, etc.	14

When the lowering of the structure was fully completed the 10 girders above Washington Avenue station were raised, and wrought-iron plates or cast-iron blocks were placed on the columns under the girders as required, the maximum amount of blocking being $7\frac{7}{8}$ ins. The grade was thus increased between Grand Avenue and Washington Avenue station from 1.4 to 1.55%, increasing the headroom for the station foot bridge and permitting engines going west to stop and start on a grade of about 1 per cent.

The original intention to retain a third track between Cumberland Street and Waverly Avenue had left the transverse girders at Vanderbilt Avenue strong enough to carry the island station; it was, however, necessary to reinforce the corresponding girders at Washington Avenue and Cumberland Street. This reinforcement was effected by placing a subgirder under the old transverse girder, the adjacent flanges being riveted together. The new grade line as established gave about the same headroom at the other two stations as at Vanderbilt Avenue. All of the track girders required special treatment, to give room for foot-bridge approaches to the island stations. The old track girders must be removed and replaced by new ones, which must be so designed as to utilize every inch of headroom available. The



had to be riggers, fitters, riveters, carpenters and track-layers, all at one time.

Eighteen other girders for new platforms weighing about 7 000 lbs. each were placed in position. These girders were old track girders from another portion of the road; the old platform girders being too light for the work, these girders were braced with new material. Thirty-two of the old platform girders, each weighing about 4 000 lbs., and the eighteen girders for new platforms were all handled with greater ease by the use of a short boomed derrick, working from the center over the side of a flat car on which it had been erected. All of the heavy material was delivered on the street and carted from and to this position on heavy trucks, the new material arriving by lighter at a dock about one mile from the work, and the old material going to the company's yard about five miles distant. Most of the handling and carting of this material had to be done at night when the street and railways were not so busy. This increased the expense and retarded the work.

The two old station buildings at Washington Avenue were used for the new stations, one at Washington Avenue and one at Vanderbilt Avenue, the two old buildings at Vanderbilt Avenue being abandoned and torn down.

The station buildings to be moved were raised up from their floors, slid over on rail skids to a heavy flat car moved by locomotive to the new positions, where the buildings were slid over into place and dropped down on the new floors previously prepared to receive them. The buildings had angle iron frames with corrugated iron sides and tin roofs laid on spruce boards; the inside was ceiled throughout with yellow pine ½ in. thick. As moved, the buildings weighed about 15 tons. The ticket offices and closets were removed and the doors and windows left in place. Light needle beams formed a frame on which the buildings rested in moving, while the raising, lowering and sliding were done with 10-ton hydraulic jacks acting against 8 x 10-in. sticks bolted across the ends of the building about 3 ft. above the floor. The car used for transportation was built for surface roads, and the heavy load set the body hard down on the side bearings. It passed easily around the curve at Clinton Avenue, and no trouble was anticipated at any other point.

Provision was made to accommodate passengers at the stations dur-

ing the changes; no station was absolutely closed to business excepting during the hours from midnight to six o'clock A. M. of the two nights when the buildings were being moved.

The work of changing the stations moved slowly, of necessity; the station girders were not placed until the re-enforcing girders, ten in number, were completed. The buildings could not be moved until all the girders were ready, and much of the carpenter work and sheet metal work and all the plumbing and painting was dependent on progress made with work preceding. Injunctions were obtained in two instances, but no serious delay in the opening of the new stations resulted in either case. Washington Avenue station was finally opened as an island station on October 17th, and Vanderbilt Avenue station on November 1st, 1893.

ITEMS.	Total expenditure.	Lowering structure. Bents 68 to 92.	Changing stations and changing grade east of Washington Avenue.
Engineering and supervision	$1 705 06	$560 00	$1 145 06
Timber for false work	1 025 25	2 354 13	997 29
Tools and other appliances	2 326 17		
New iron work left in structure	11 051 20	193 70	10 857 50
Cartage and transportation	1 027 87	138 37	889 50
Moving electric wires, etc	508 35	200 00	308 35
Labor account	10 011 79	2 545 22	7 466 57
Personal injuries	3 50	1 00	2 50
Changes in station building and stairs:			
Iron work	5 515 58		
Carpenter work	4 547 54		
Roofing and sheet metal work	1 465 11		
Plumbing	272 39		
Painting	666 93	.....	12 467 55
Total work completed	$40 126 74	$5 992 42	$34 134 32
Estimated cost of completing Cumberland Street station:			
Erection of stairways, etc	600 00		
Carpenter work	3 000 00		
Sheet metal work	900 00		
Plumbing	300 00		
Painting	400 00		
Heating apparatus	200 00	.....	5 400 00
Grand total	$45 526 74	$5 992 42	$39 534 32

New station buildings would have been more commodious and ornamental than the old ones; about $3 000 was saved, however, by the use of the old buildings, which, with extensions and other changes made, satisfy all the ordinary requirements. The canopy posts from the old

station platforms were again used, the canopy trusses and roofs being new.

Only one accident occurred on the entire improvement; a man fell in securing one of the re-enforcing girders at Cumberland Street and was slightly injured.

Great credit is due to the workmen employed for skill and zeal displayed. The roadmaster deserves special commendation; he was almost continuously on the work in its serious stages; his familiarity with the movement of trains and handling of men and material was intimate and thorough, and he devised many expedients of great service in avoiding delay and expediting the work.

The cost of the entire improvement was as shown in table on page 373.

No allowance whatever has been made for tools and material left over from the work, which will be valuable for other work.

The following figures have been made in the endeavor to ascertain the value of the improvement to the road. Aside from the semi-sentimental betterments, that no uncertainty can now arise as to which stairs to take for up or down trains, and that passengers are often spared the necessity of crossing crowded or muddy streets, aside from all this, what has been saved?

The direct saving from the change to island stations may be placed as follows for the two stations:

Services of four station agents, for two stations, at $1.75	$7 00	per day
Heating and lighting, two stations, at 50 cents	1 00	"
Total saving per annum, $2 920, at	$8 00	"

The annual interest at 5% on the cost of the work to date is $2 006 34, that is, the saving at stations alone would have paid the interest on the entire cost if it had been 45% greater; or the saving from the change of stations would have paid the fixed charges due to these changes and carried those of the cost of change of grade if the latter had cost four times as much as it did.

There must be a positive economy in the operation of trains due to the lowering of the grade; it is, however, difficult to determine its equivalent in dollars and cents. Considering only the power required to lift the trains on the two grades, we know that where trains were formerly lifted vertically $14\frac{4}{10}$ ft. in 770 ft., they are now

lifted the same height in 1 330 ft. The mean of many observations placed the speed of ascent at 15 and 18 miles per hour respectively. Formerly the trains were lifted in $\frac{583}{1000}$ minute, and they are now lifted in $\frac{839}{1000}$ minute, the horse-power developed in the two cases being 104.8 and 72.8, taking the weight of each train at 70 tons, including engine. It was necessary to maintain 32 H. P., or 44% greater efficiency in the engines on the old grade than on the new one, to accomplish the same work of lifting the train $14\frac{1}{10}$ ft., the resulting gain being due to the lengthening of the time in which the work is done.

About 400 trains are lifted every day, and the additional power was maintained for every train. We do not know just what this class of power costs per unit; it probably is not less than the average cost of the unit horse-power maintained for all the engines on the road in regular service, and this average cost approximates to $\frac{25}{1000}$ cent per horse-power. On the assumption that this figure will cover the cost per horse-power, the cost of maintaining the additional power required for the old grade would be $\frac{8}{10}$ cent per train and the saving due to the change of grade will be $\$.008 \times 400 \times 365 = \$1\ 168$ per year.

If, now, this sum be added to the saving from changing the two stations, the total saving will be $4 088, and the money would have been well invested had the improvement cost twice the amount actually expended. It also appears from these figures that the change of grade would have been a profitable one to make if it had been done of itself at four times its actual cost.

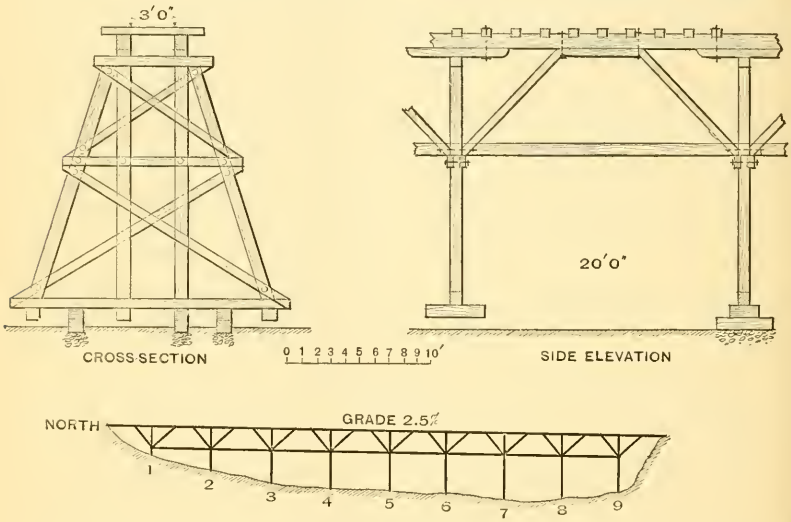
As to the Cumberland Street station, 15% of the business done at Vanderbilt Avenue station will meet the fixed and operating charges due to completing and using the new station.

The only serious objection to opening this station at once is the expense and delay due to making train stops. There can be little doubt that this objection will soon be overcome by the increase of business, and that it will be found expedient and profitable within a reasonable time to complete the station for use. Should this station, when opened, be ordinarily successful and do two-thirds only of the business done at Vanderbilt Avenue, it will, itself, earn 125% annually on the cost of the change of grade, and 20% on the cost of the entire improvement.

DISCUSSION.

Emile Low, M. Am. Soc. C. E. (by letter).—Mr. Nichols' paper brings to my mind an experience I had some 16 years ago (1878) in lowering a trestle on what was then known as the Pittsburg Southern Railroad, successor to the Pittsburg, Castle Shannon and Washington Railroad, a narrow-gauge line between Pittsburg and Washington, Pa. A portion of this railroad now forms part of the Wheeling Division of the Baltimore and Ohio Railroad. The trestle in question was situated about 1 mile south of Thomas Station, and on a descending grade, going south, of 132 ft. to the mile.

PITTSBURG SOUTHERN R.R. PLAN SHOWING METHOD OF LOWERING HAMILTON TRESTLE 2.



The standard trestles of the Pittsburg Southern Railroad were built to the following general dimensions : Span, center to center of bent, 20 ft.; plumb and batter posts, 10 × 10 ins., the batter of the latter being 4 ins. to the foot; stringers, 10 × 12 ins., strengthened by long corbels and knee braces. The foundations were usually mud blocks or sills, resting upon broken stone.

The proper elevation of the mud blocks was indicated by suitable stakes driven in the ground at each end of the sill, the top of the stakes corresponding to the bottom of the sill. In setting the stakes for this particular trestle, through the inadvertence of one of the assistant engineers, the stakes for bent No. 7 were driven, and their tops left 1 ft. too high.

The foreman in charge of the carpenter force erecting this trestle began at bent No. 9, which was properly erected, as was also bent No. 8. When bent No. 7 was set up, of course it was too high. Bent No. 6 came next, and was again correct. The foreman, without consultation, and on his own responsibility, raised bent No. 6 to come in surface with bents Nos. 7 and 9, and then raised bent No. 8 to suit.

It may be remarked here that none of the engineering force of the railroad were on the ground during the erection of this trestle, or this would never have occurred. Bents Nos. 5, 4, 3, 2 and 1 were raised in order, and of course did not line on account of the new order of things. Nothing daunted, the foreman raised these last ones, being possibly two or more feet too high at the north end.

Proper stakes were driven at each bent, and why the foreman did not notice that by lowering bent No. 7 everything would have come all right baffles explanation. The consequence was that the whole trestle was cocked up on a row of blocks, some 2 or 3 ft. high.

The erection of the trestle only occupied a few days, and its peculiar arrangement was noticed by me on a trip over the line a few days after its completion. The carpenter force had been disbanded. It was my desire to put the trestle where it properly belonged, and this work I accomplished as follows : The only force I was able to command was an Englishman, named Burton, and his two sons, the owners of a few horses and carts, which had been engaged on the work of grading of the same road.

My first instructions were to obtain from a neighboring saw mill a supply of 1-in. boards, which were sawed in lengths varying from 2 to 4 ft. Fortunately none of the elevation stakes set for the bottom of the sills had been moved. These were duly pointed out to my man, and their purpose fully explained.

Then I further instructed him to take out one by one the mud blocks, lower each to its proper level on the broken-stone foundation, and then carefully fill up the intervening space with the 1-in. boards, using the longer ones at the bottom, the shorter ones on top. As soon as one block was properly fixed, another block was taken out, placed in position, and the space filled up with 1-in. boards.

This procedure was followed until every block had been correctly placed, the trestle then remaining as originally erected, except that it was resting upon these 1-in. boards, and these in turn on top of the mud blocks.

The most difficult part of the work yet remained, and that was the removal of the boards and the consequent lowering of the trestle. No appliances of any kind were at hand, such as jacks, etc.

Recourse had to be had to long, heavy levers, cut from trees in the vicinity of the trestle. With these and blocks for fulcrums, the 1-in. boards were gradually withdrawn, thus lowering each bent in

turn 1 in. This method was kept up until the trestle rested upon its final foundation, and was true to the original contemplated grade. I was not present when the work was done, but it was entirely performed by the three men mentioned, none of whom were carpenters, and had never been engaged in work other than that of grading.

The work was so skillfully executed that not a joint was opened in the entire structure. Trains were running over the trestle during the whole time that the work of lowering was in progress. The work only occupied a few days, and the resulting expense, I suppose, did not exceed $20 to $25.

John Thomson, M. Am. Soc. C. E. (by letter).—In regard to the closing paragraphs of this paper, I do not think that Mr. Nichols claims enough advantage for the work accomplished. As I understand it, however, the data furnished are not sufficient for a proper comparison. But from an assumption based upon the figures of his paper, I find that the advantage measured in point of time is about 20 per cent. Thus, it is not stated whether there has been any diminution in the speed of approach of the new grade. If so, this would be an element of advantage to the new. Neither do I find the time given for traversing the level stretch of 560 ft. after the old grade had been passed. On the assumption of a uniform rate of 15 miles an hour, however, and taking 0.583 minute for the old grade with a distance of 770 ft., and of 0.839 minute for the new grade with 1 330 ft., this would make the time for the difference in distance 0.424 minute, or 1.007 minutes for the entire distance. Hence, 1.007 — 0.839 gives 0.168 minute, or $\frac{.168}{.839} = 20\%$ advantage in time. And this is, by the way, a proof of the train speeds quoted, namely, 15 miles an hour for the old grade and 18 miles an hour for the new; that is an advantage in speed, on grades, of 20 per cent.

Of course, my only object in this is to bring out the additional data which evidently are necessary to give a more satisfactory solution; because, judging the moving of these trains as if they were, say, the sliding block in a cam, then I am quite of the opinion that there would be a greater actual advantage than is claimed by Mr. Nichols. And I may suggest that the expression of raising the train through the height of 14.4 ft. is somewhat misleading unless closely associated with the two elements, time and linear space; because, if it were simply a question of vertical height and time, then the work, in foot-pounds, necessary to elevate the trains vertically could probably be otherwise accomplished at less expenditure than by running the trains over a linear distance of 700 to 1 300 ft.

Were any indicator tests made of the engines while traversing these grades before and after? Would not this have told the story pretty effectively in terms of coal consumption?

E. E. Russell Tratman, Assoc. M. Am. Soc. C. E. (by letter).—While the paper by Mr. Nichols is interesting and instructive in its record of the design and carrying out of an engineering work, it seems to me that its chief value lies in the references and calculations made as to the economic side of the questions involved. We see constantly in Society transactions and technical papers the descriptions of works designed and constructed, but it is rarely that the writers present or discuss the economic points. While it would not be fair to assume that they have ignored this side of the subject, it seems certain that railway economics and engineering economics (not economies) are not studied as they should be.

Taking this question of the stations of elevated railways, it is not likely that the economics of station arrangements were gone into in the original laying out of these roads, or, with such results as those given by Mr. Nichols, it would probably have been decided to build more stations on the island plan, though, of course, local conditions prevent the adoption of any one standard throughout. The Chicago and South Side Railway, which owns its right of way through the blocks, has its stations under the structure, on the street level, so that only one ticket agent and ticket chopper are required, while at the same time a separate platform is retained for each track. It is also worthy of note that the New York elevated roads have one station in a building on the street—the ticket offices, etc., of the Fulton Street station being on the second floor of the United States Hotel building, from which there are passages and stairways to an island platform. The substitution of turnstiles for ticket choppers is another question in the economics of operation.

The paper also brings out the fact that many comparatively small works involve much study and many difficulties. Thus, while the change of grade was in itself no great work, yet the carrying out of a complicated series of operations so as to avoid interference with the heavy traffic made it necessary to foresee and provide against many possible troubles, and especially made it necessary to have a well-organized gang. As shown by the paper, only a limited number of men could be worked, and they had to be able and ready to turn their hands to all sorts of work; while, during the operation of lowering, it was necessary that each man should know his particular duty and do it at the proper time. Upon the organization and handling of gangs for difficult work depends much of the engineer's success, and it should not be forgotten that to such gangs belongs a good share of the credit for the execution of many of our important works.

J. J. R. Croes, M. Am. Soc. C. E.—The author's description of the methods employed in the carrying out of the work of construction is exceedingly interesting and very valuable for reference. The difficult work of lowering a long section of elevated railroad track without inter-

fering with the passage of trains is so clearly and fully described that there does not appear to be any comment necessary, and criticism of the methods cannot well be made by any one without knowledge of the circumstances attending the work. So far as can be judged from the paper, the work seems to have been executed with good judgment throughout. The advantages to be gained by having intertrack stations on a line of city transit are not overstated by the author, provided the circumstances are such as to permit of their being used to advantage, and with increase of travel the advantages of intertrack stations are greatly increased. This is chiefly due to the less number of men necessary to be employed at the stations. At stations where the traffic in both directions is very heavy, an intertrack station is very much to be preferred as affording opportunity for the construction of exit platforms on the outside of the tracks, enabling passengers to pass out from the trains without interfering with the incoming passengers. This, to be sure, has not been taken advantage of in the existing elevated railroads on New York island, the intertrack stations of which are provided only with one platform, with the result of great confusion and interruption to both incoming and outgoing passengers. It is said to be stated by officers of the roads that the objection to the construction of such outside exit platforms is that the owners of adjoining property would claim additional compensation for the supposed obstruction to light and air caused by their erection.

The relative cost of intertrack and side-track stations is exemplified by the annual reports of the various elevated railroads for the year 1891, as follows: Suburban Rapid Transit Company, operating 4 miles of line with 11 stations, all intertrack, carried 10.74 passengers per train-mile, and the cost of station service for each station was $2 064. The Kings County Elevated, operating 8.34 miles of line with 24 stations, mostly side track, carried 13.71 passengers per train-mile, and the cost of station service was $3 921 41 per station. The Brooklyn Elevated Railroad, operating 17.93 miles of line, carried 12.27 passengers per train-mile, and the cost of station service was $2 537 24 per station. The Manhattan Railway operating 32.40 miles of line, with 98 stations, carried 23.77 passengers per train-mile, and the cost of station service was $5 909 62 per station, all but six being side-track or double stations. Making every allowance for increased cost due to additional travel, the maintenance of intertrack stations cannot be other than much less than that of side-track stations.

But it must be borne in mind that intertrack stations necessitate the occupation along the whole line of a much greater width of right of way, and that they interfere very materially with the possibilities of real rapid transit on a long line, for the carrying out of which a third track passing by at least three-fourths of the stations without stopping is necessary. It is true that in localities where a large amount

of long distance travel in both directions simultaneously exists, four tracks are necessary, or an entire double system, but where, as in both New York and Brooklyn, the great bulk of the travel during two or three consecutive hours is in one direction, only three tracks are really needed, and, in any street which is wide enough to accommodate three tracks at all and rapid transit is essential, it will prove cheaper and better to space the tracks for ordinary traffic far enough apart to admit of the laying of a third track between them, and to put the stations outside of the tracks and not between.

As regards the increased economy in operation of trains due to the reduction of grade, the argument appears to be more theoretical than practical when applied to elevated railroad service where the runs are so short between stations and the speed of the train must be checked before the effective capacity of the locomotive for a long run has been reached. That the coal consumption of engines ascending the grade would be somewhat reduced by the flattening of the grade, there can be no doubt; but it is a question whether that is not balanced by the increased consumption necessary in operating trains in the opposite direction. Whether the change of grade has resulted in diminishing the coal consumption in the locomotives can only be discovered by comparing the consumption of coal during any six months since the change of grade with the coal consumption on the line during the same six months of the year preceding the change of grade, not with the six months immediately preceding the change, for the consumption of coal by the elevated railroad locomotives varies very much with the temperature of the outside air, and the amount of coal consumed per mile during the different months of the year varies almost directly as the mean of the thermometer for those months. The attempt to calculate theoretically the amount of saving effected in horse-power and in cents per horse-power without having any actual figures of results obtained by which the computations can be verified, introduces into this eminently practical and instructive paper a hypothetical element which might with advantage be omitted.

H. W. Brinckerhoff, M. Am. Soc. C. E.—In estimating the economy in operation, due to the flattening of the grade which the paper describes, the author asserts that "it was necessary to maintain 32 H. P., or 44% greater efficiency in the engines on the old grade than on the new one to accomplish the same work." He then assumes that the cost per unit of the horse-power thus saved is equal to "the average cost of the unit horse-power maintained for all the engines on the road in regular service," which he gives at $\frac{25}{1000}$ of a cent.

To take up the last point first; in response to an inquiry from the writer, the author says: "The cost of the unit horse-power was obtained by dividing the cost per train-mile by the horse-power developed per mile." Just what "horse-power developed per mile" can mean, or

why it should be any different from horse-power developed per inch, is not at all clear, especially when it is considered that the cost per train-mile is, within ordinary limits, not materially affected by the rate of speed, while the horse-power is very closely proportional thereto, so that, by the author's method of computation, the less the speed, the more it costs per "unit horse-power."

If we take 50 cents as probably a reasonable figure of cost per train-mile for 70-ton trains, we will find that for a cost per "unit horse-power" of $\frac{25}{1000}$ of a cent, there must be $\frac{50 \times 1\,000}{25} = 2\,000$ H. P. "developed per mile," suggestive, perhaps, of 50 engines developing 40 H. P. each, as at an average tractive resistance of 10 lbs. per ton, a 70-ton train would, at 20 miles per hour, or 30 ft. per second, require nearly 40 horse-power $\left(\frac{70 \times 10 \times 30}{550} = 38 \text{ H. P.}\right)$ for its propulsion.

It is, however, hardly worth while to spend time in conjectures as to what such unusual expressions and computations may be imagined to mean when the fundamental statement is so obviously erroneous. The old grade did not make it necessary to maintain 32 or any other horse-power more or less than the new one. The horse-power required to ascend a grade with a given load depends just as much on the speed as on the steepness. If made so steep that the engine can barely crawl up, it may take much less horse-power to ascend a given grade than if made so flat that practically full speed could be maintained, which, according to the author's mode of reasoning, would prove the economy of heavy grades. To take the case in point; if the speed had not been increased after the grade was flattened, only 60.6 H. P. would have been required to surmount it, and a much greater economy could have been figured out, while, if the speed had been increased to 26 miles per hour, the new grade would have been surmounted in the same time that the old one had been, requiring the same horse-power, and, consequently, showing no economy whatever, and a still higher speed would show a positive loss.

This ought to be enough to show the fatal fallacy of this mode of reasoning, which seems to be based on the assumption that horse-power is, in itself, a measurable quantity, and, as such, can be saved, with a resulting cash gain; whereas, horse-power is merely a rate of doing work, and can no more be saved or accumulated than a rate of interest can be deposited in a savings bank. It must follow, also, that, as horse-power is not a quantity, it can have no real unit, and that all calculations involving a "unit horse-power" as something different from 1 H. P., are meaningless and misleading. The only real and valuable quantity dealt with in the foregoing calculations is the train-mile. This represents work done, and, if our previous assumptions are correct, equals $70 \times 10 \times 5\,280 = 3\,700\,000$ ft.-lbs.

It will be noted that the correctness of our reasoning is in no way dependent on the correctness of these assumptions, which are merely used for convenience of illustration. Indeed, while 10 lbs. per ton is, perhaps, ample for the average resistance of a moving train, even including grades, it would, for elevated roads, have to be largely increased, perhaps even doubled, to allow for the large amount of energy that is absorbed by the brakes in the frequent stops, and which has to be redeveloped by the engine in getting up speed each time.

The work done by the engine in one ascent of the grade is obviously $70 \times 2\,000 \times 14.4 = 2\,016\,000$ ft.-lbs. plus the train resistance multiplied by the length of the grade. As the sum of this latter quantity plus the resistance on the level track is necessarily a constant, and the former quantity is independent of the steepness of the grade, it follows that, if we leave out the saving in repairs due to shortening the time of maximum effort for the engines, the actual economy effected by this particular flattening of grade is that due to the shortening of three-fourths of an inch in the total length of the line. As this is effective both ways, or for 800 trains a day, it would give in a year $\frac{3 \times 800 \times 365}{4 \times 12 \times 5\,280} = 3\frac{1}{2}$ train-miles, or to be liberal, an annual saving of, perhaps, $2.

G. Leverich, M. Am. Soc. C. E.—It would seem that engineers who are not locomotive runners are likely to be confused by the trend of this discussion. Generally, there is no difficulty going down hill; it is going up hill that causes trouble, and yet one may conclude from what has been said that the degree of grade to be overcome is unimportant, which is a manifest error.

On any railway line, the maximum grade determines the hauling capacity, and consequently the weight and steam-making power of the locomotives to be used, and they will be worked with the greatest economy, taking into account the costs of operation and repairs, and their length of service, when this grade most nearly corresponds with the profile of the other parts of the line. An abatement of grade may, therefore, permit the selection and use of locomotives more nearly adapted to the general work of the railroad than otherwise were possible.

Virgil G. Bogue, M. Am. Soc. C. E.—I would like to ask Mr. Nichols, if the time referred to in each case would bring his train out to the same point? If not, there must be a certain expenditure of horse-power in going over the level track, which, it seems to me, should be added to the smaller sum total of horse-power to get a perfect result. This would reduce somewhat the saving.

I think the paper is a very complete one. The question of repairs of these stations has been left out of consideration; I should think that the repairs of an island station would be somewhat less than for a double station.

G. H. Blakeley, Jun. Am. Soc. C. E.—I think that we can, in this discussion, refer with profit to common experience. Suppose we have a weight to raise to a fixed height in a definite time, and we are using an engine which can just accomplish it, if the time of the lift can be extended twofold, we certainly can employ an engine of half the power. This is self-evident. In either case the amount of work done is the same, as the product of the weight by the distance raised is the same for both instances, or, mathematically speaking, the number of foot-pounds of work accomplished is identical. The horse-power in the second instance is only one-half of that employed in the first case. The horse-power is not a measure of the amount of work; it is a measure of the rate of doing work.

The subject under discussion presents a similar case. The weight of the trains and the vertical distance raised, remain the same. The only factor that is changed is the time, which has been increased. The amount of work done remains the same. The change is in the rate of doing it.

A pound of coal represents a certain number of heat units, a certain number of foot-pounds of work. Theoretically, the consumption of coal necessary to accomplish a certain definite amount of work is calculable and does not depend on the rate of doing the work. It requires about 4 pounds of coal per hour to develop 1 H. P. In the instance under discussion, before the grade was changed, it required 104.8 H. P. acting $\frac{583}{1000}$ minute to lift the train 14.4 ft. The coal consumption would then be:

$$\frac{104.8 \times 583 \times 4}{1\,000 \times 60} = 4.07 \text{ lbs.}$$

In the second instance the same train is lifted the same height in $\frac{839}{1000}$ minute, using 72.8 H. P. The amount of coal consumed will then be as follows:

$$\frac{72.8 \times 839 \times 4}{1\,000 \times 60} = 4.07 \text{ lbs.}$$

As was to be expected the coal consumption is the same in either case.

From the facts developed by the discussion it seems quite evident that under the old condition the engines were worked up to, if not exceeding, their capacity. The easement of the grade reduces the energy required, and should practically result in a saving in the amount of the annual repairs to the locomotives. It is not an easy matter to determine how much this saving is, but it is certainly not inconsiderable in this case.

P. F. Brendlinger, M. Am. Soc. C. E.—Mr. Nichols has given the Society this evening a rare treat. He has shown us a practical illustration in detail, of performing, of what no doubt seemed to him, a very difficult undertaking, and the problem no doubt caused him long

hours of serious study. Yet, like many other problems, it seems easy and simple after the work is completed.

The winding up of the paper where Mr. Nichols goes into the theoretical and determines the amount of coal saved by the change of grade seems to my mind to introduce a problem that can only be solved by actual trial on grades much longer than the one changed. If, for example, we have a grade of 2 ft. per 100 ft. for 1 mile, and another of 1 ft. per 100 ft. for 2 miles, both grades on a tangent, we could then by trials demonstrate practically whether the coal consumption on one grade would be greater than the other, but in this paper we have the grades extending only 770 and 1 330 ft., hence the problem is rather difficult to solve practically.

Theoretically we have the same amount of energy expended to lift the train whether the work is performed in 770 ft. or in 1 330 ft., the height to which the load is lifted being identical in both cases. The ratio of work performed per foot horizontally on the two grades being as 1 330 is to 770, or, approximately, 73% greater on the heavier grade than on the lighter. Practically we find the case is somewhat different as the resistance of the train is not double on a 2% grade what it is on a 1 per cent. The resistance due to the grade alone is always at a uniform ratio, but to each amount due to the grade must always be added the constant due to the horizontal resistance.

Thus while a 2% grade gives 40 lbs. resistance per ton per foot raised, and a 1% grade 20 lbs., yet, owing to the horizontal resistance, we have, on a 2% grade, a resistance of 47 lbs. per ton at a 15-mile speed, and 27 lbs. per ton on a 1% grade. In calculating the resistances on the old and new grades of the Myrtle Avenue line, I will take the average of both grades. I find in one case the elevation of 14.4 ft. is overcome in 770 ft. or at the rate of 1.87% grade per 100 ft. In the other or new grade the 14.4 ft. overcome in 1 330 ft. or 1.08% grade per 100 ft. The resistance of the train on the heavier grade at a speed of 15 miles per hour is about 45 lbs. per ton and on the lighter grade about 29 lbs. per ton, or in other words we have practically only 55% greater increased resistance on the 1.87% grade than on the new grade, while as I have shown above that theoretically we have 73% more energy expended on the heavier grade than on the lighter. Now, to overcome the resistance on any grade requires engine pull which is produced by the consumption of coal, water, etc. If the coal consumption is uniform or constant for every pound of train resistance, then the consumption on the lighter grade for 1 330 ft. would be greater than on the heavier grade for 770 ft., but to the coal consumption for the heavier grade must be added the consumption of coal due to the resistance of 7 lbs. per ton on the 560 ft. of level grade. This may bring the total coal consumption greater on the old than on the new grade. As I have before stated a trial of considerable length of

time on long grades, is necessary to determine whether any coal is saved on grades as herein mentioned.

There is no question in my mind that an immense saving in engine wear, running of trains, etc., results in having the grade changed, and much heavier trains can be hauled over the road if there are no other grades on the road as heavy as the one that was changed. As to a saving of coal I leave that to the actual practical demonstration in a year's operation of the road.

W. E. Belknap, Jun. Am. Soc. C. E. (by letter).—The term "horse-power" expresses a rate, a number of units of work expended in a unit of time, 33 000 lbs. lifted 1 ft. per minute. To store up or save in bulk a rate of work is as inconceivable as to store up and save in bulk a rate of interest.

The work expended in moving a train in the same direction between any two points on a road is always equal to the horizontal resistance—the friction over the horizontal distance—plus the vertical lift, a result not at all affected by changes of grade between these two points so long as they retain their relation of altitude. How it can be shown in this case, using the factors of time, weight, horizontal distance and lift, that any work is saved is difficult to see.

That there was a small saving of coal due to this reduction of grade is highly probable. It is a quantity whose determination depends on a comparison of the efficiency of the engine on the original grade with its efficiency on the new grade.

Assuming that the engine was designed to work at its highest efficiency under the probable average load, then (taking the train weight to be always the same) there must be some one certain grade on which that load would always obtain, and on any other grade the load would be more or less than this—that is to say, there is only one grade on which the engine will work at its highest efficiency, and this is the grade which was probably assumed by the designer of the engine when he considered the question of efficiency. Any change in the grade in question bringing it nearer this assumed grade obviously betters the working conditions of the engine, gives it a higher efficiency for the period of time it is on the grade than it had before; and since in the end the same distance is traversed, the same altitude attained, the same work done, there will be a saving of coal in proportion to the increased efficiency on the new grade. How much it would actually be in practice under the ever-varying conditions of wind pressure, number of passengers, speed, temperature, etc., would be very difficult to determine unless the old grade had increased the load far beyond the efficient working capacity of the engine.

O. F. Nichols, M. Am. Soc. C. E.—The cost of operating railway grades has received much attention, without, however, developing results directly applicable to the example presented in this paper.

Some of the literature on the subject is verbose and confusing, often speculative and sometimes erroneous. The difficulty of avoiding these stumbling blocks is apparent from the discussion in hand. It would seem unwise to cumber the record with explanatory matter, and far better to allow misinterpretation, and even misstatement, to go unquestioned than to enter upon a disputation interesting only to the disputants.

The economy claimed for the change in grade is believed to be conservative, if not far within limits, and was somewhat cautiously enunciated in the hope that the author might himself be instructed by those more experienced and skilled in the theory and practice of railway construction and operation. In this respect the discussion has fallen far short of the expectation.

It is simply astounding to find engineers contending that nothing has been saved by this reduction of grade, that indeed one grade is just as economical as another, if not a little more so. This suggests the question, whether the trunk lines are not wasting millions of dollars in simply lengthening the distance in which elevations are overcome on their lines. After such an exhibition, one does not so much wonder that many glaring errors occur in the use of grades, or that railway operating expenses vary so much.

There seems to be a confusion of ideas in the minds of some of the contestants as to the fundamental principles of the problem presented. That the entire work in foot-pounds exerted in raising the trains is the same, regardless of percentage of grades, is elementary, if not axiomatic. As in all similar problems in mechanics, time is quite as important as distance and weight, and is the very bone and sinew of this matter.

Our friends fail to realize that horse-power has no existence without time, that it is a measure of work because it is itself work; not merely something evanescent and inscrutable, but something tangible and real, that may be bought and sold by the day or year, by the inch or mile, or by any other standard which has time as one of its functional elements; that, if it cannot be stored up or deposited in a bank, it costs just as much as if it could, in the daily and yearly barter and sale of the commercial world.

In some recent dynamometric experiments in France the results are given in horse-power per ton of train in ascending grades at various speeds. They show, among other things, that the horse-power required varies very rapidly with the speed. Unfortunately these experiments were made on low grades at high speeds, otherwise they would be valuable in this connection; as far as they are applicable to the problem, they tend, in a general way, to confirm the methods used and the results obtained in the paper under discussion.

There certainly is a decided economy in this reduction of grade, and no amount of obfuscation can completely conceal it; like Banquo's ghost, it will not down; it exists like the kernel in the nut, and may be, at least approximately, determined if we have the capacity to crack the

nut. It is minute, perhaps, for each train, and consequently more difficult to find experimentally. If we consider only the saving in coal, and assume the entire amount claimed as saved to be expended in coal, it would correspond to 3½ lbs., or, say, 11 cu. ins. per train, an amount so small as to be indeterminate in any experiment applicable to the case.

The difference in horse-power on the two grades is merely a difference in foot-pounds, divided by time and Watt's arbitrary constant, and should not be confused with engine performance. The engines may, indeed probably do, not develop as much horse-power on the high grade as on the low, but they are longer at it, so that the problem in any form is essentially one of time.

The first calculations for economy by the reduction in grade were based solely on the saving of time due to actual running of trains. The 560 ft. of level track at the summit of the old grade was run at a speed not exceeding 20 miles an hour ; the saving of time over the total distance of 1 330 ft. was then about one-tenth of a minute by the new grade. Several hundred hours were thus saved per year ; that is, not only do the engines arrive at the summit of the new grade in better condition than on the old one, but they then have considerable available time to their credit. The running time between the two adjacent stations is diminished nearly enough to provide for the dead stop at one of the stations. Taking the average speed at 13 miles an hour and the cost per train-mile of running trains at its actual value, 26 cents, there results a saving of something like $600 for the change of grade, without considering the horse-power involved.

This first calculation is now given in order that some of its constants may be used in the consideration of one of the suppositious illustrations of the discussion. "Suppose," says one of the contestants, "that a speed of 26 miles an hour is maintained (by some abnormal engine) on the new grade, the horse-power will then be equal on the two grades, etc., etc.; and if the speed be increased above 26 miles an hour, there will result a positive loss," due to the "improvement." The inevitable economy would, under this hypothesis, simply assert itself in another way. If the time spent on the grades is equal, engines on the new grade would have the time of the entire run over the 560 ft. of level track to their credit. This for the year would correspond to 15 295 train-miles, which at 26 cents, as before, corresponds to about $4 000, from which should be deducted the increased cost of maintaining the speed of 26 miles an hour, and then represents the saving from the reduction of grade, on this supposition.

It should be noted that the obvious saving in coal on engines descending the new grade is not counted in the total saving, its amount being indeterminate. The engines were formerly obliged to run the 560 ft. of level track under good steam-pressure ; while now but little steam is required, excepting to control the train, after it has passed the summit of the new grade.

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737.

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THE DUNNING'S DAM, NEAR SCRANTON, PA.

By E. SHERMAN GOULD, M. Am. Soc. C. E.

READ OCTOBER 17TH, 1894.

WITH DISCUSSION.

The city of Scranton, Pa., with a population of about 85 000, is supplied with water by two private companies, namely, the Scranton Gas and Water Company and the Providence Gas and Water Company. The operations of the latter are confined to the annexed districts of Providence and Green Ridge. By far the greater portion of the city, together with the most important manufacturing establishments, are supplied by the Scranton Gas and Water Company.

At the time of the construction of the works about to be described, the water furnished by this corporation was drawn entirely from Roaring Brook, a large stream emptying into the Lackawanna within the city limits. It was delivered by gravity, the elevation of the distributing reservoir being sufficient to supply all but a few very elevated portions of the city, without pumping.

Prior to 1887 there was but one reservoir, situated some four miles above the city, of a capacity of about 80 000 000 galls. The water consumption was probably in the neighborhood of 6 000 000 or 7 000 000

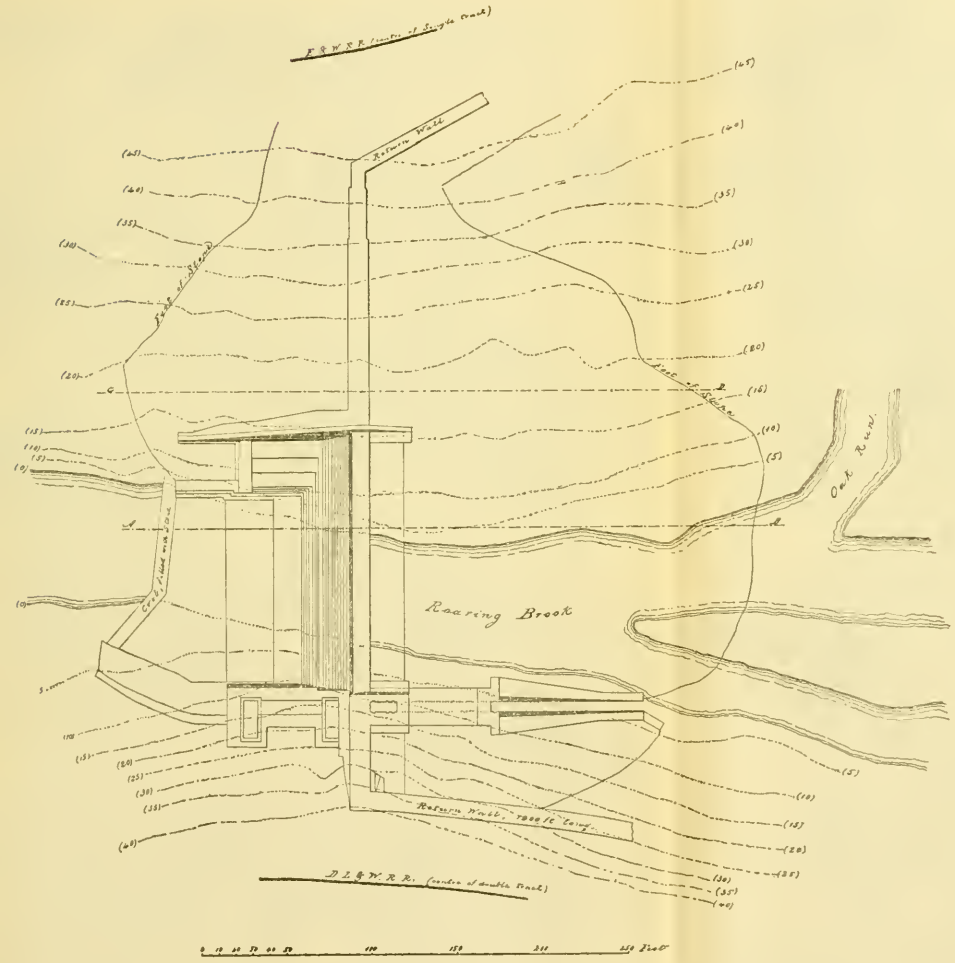
galls. per day, so there was but little storage. It is true the company controlled the right to the use of the water of Lake Henry, which could be drawn upon in an emergency for about 400 000 000 galls., but, the water-shed of this lake being small, it could not probably be emptied and refilled every year, and was, therefore, not available as a regular supply.

In 1886 a severe drought, during which the reservoir above mentioned was drawn down several feet, and a water famine only averted by opportune rains, gave warning that storage was becoming necessary. The writer was accordingly engaged by Mr. W. W. Scranton, president of the company, in the summer of this year, to design and build a storage reservoir of about 350 000 000 galls. capacity on Oak Run, a small stream emptying into Roaring Brook about 10 miles above the city of Scranton, and draining, above the proposed reservoir, an area of only some $2\frac{1}{3}$ sq. miles.

The dam forming this reservoir presents certain interesting features, but, as they were all repeated upon a much more important scale in the Dunning's Dam about to be described, they will not be mentioned here, further than to state that the dam was completed and the reservoir filled inside of one year from the time of commencing work, and that the actual total cost of the same was $65 392 76, or about 7% inside of the estimate.

The building of the Oak Run reservoir was intended only as a temporary expedient, to provide for immediate contingencies. Prior to and during its construction active steps were taken for the building of another and much larger one on the main stream. As is frequently the case, among all the possible sites for a large dam, one stood out in bold relief as being preferable to all the others, the topography of the valley of Roaring Brook clearly indicating the one most advantageous location for a high dam. The approximate site being thus fixed, the exact position for the axis of the dam was determined by means of an accurate contour map, and subsequently verified on the ground. This map, which was preserved in duplicate, represented the original surface of the ground before any work was done, and thus afforded a ready means of calculating all subsequent excavation and embankment. Test pits were also dug, and a good general idea of the ground obtained before beginning work.

The track of the Delaware, Lackawanna and Western Railroad fol-


Roaring Brook
Oak Road
Reservoir Wall
Reservoir Wall, 1000 ft long
D. L. & W. R. R. (center of double track)

lows the left, or southerly, bank of Roaring Brook, through the greater part of its course, and, at the point selected for the dam, approaches very near to the stream. On the right bank the Erie and Wyoming Railroad follows the course of the stream to the point where Oak Run joins it. The track then leaves Roaring Brook to follow the right bank of Oak Run, skirting along the reservoir already mentioned. The location of the dam and of the above-named railroads are shown on Plate LIV.

The nature of the ground at this point was somewhat peculiar, and seems to be characteristic of the streams in this section. On the southerly, or Delaware, Lackawanna and Western side, rock crops out, being apparently the Pocono or Catskill sandstone. This continues to about the middle of the stream, where it breaks off abruptly, the remainder of the bed of the stream and the opposite bank being mostly a stiff clay. This formation, which is shown on Fig. 2, Plate LV, involved the building of the dam half on rock and half on earth, with an abrupt jump from one to the other, the transition point occurring near the center of the spillway.

This outcrop did not extend indefinitely up and down stream from the point selected for the dam. It constituted simply a projecting nose jutting out into the stream, the rock, both above and below, receding considerably from the bank.

The abrupt breaking off of the rock in the middle of the stream was certainly a very unfavorable circumstance as regards a solid and uniform foundation, but the existence of rock on at least one side was regarded as a great advantage, for it made it possible to get a good and permanent foothold for the tower, and gate chamber, and for the raceway for the discharge pipes, with a great saving of masonry. From the point where the rock broke off, a center wall of masonry was carried along, which formed the core of a heavy earthen embankment upon the northerly, or Erie and Wyoming, side.

In planning the dimensions of the dam, the existence of the two railroads, particularly the Delaware, Lackawanna and Western, presented a serious complication of the problem, and gave rise to the most interesting engineering feature of the work. In order to secure the desired capacity—twelve hundred millions of gallons—it was necessary to raise the lip of the spillway 7 ft. above the level of the Delaware, Lackawanna and Western track at that point. It was impossible, there-

fore, to terminate the dam at the track, and the only way to accomplish the desired end was to carry the main dam up to the necessary height, and then build a side wall to it, running approximately parallel to the track and continuing until the grade of the road, rising at the rate of about 1 in 100, should carry it above the high-water level in the reservoir. This wall ran some 1 200 ft. to a projecting knoll of compact clay loam, into which it was deeply embedded.

The same necessity for a side wall existed upon the opposite bank, but on this side the wall was much shorter, only about 600 ft. long, as the level of the Erie and Wyoming track at this point was about 8 ft. higher than that of the Delaware, Lackawanna and Western. As there was no suitable stopping place for this wall inside the reservoir, it was turned across and under the track, and carried well into the solid bank on the other side.

A somewhat detailed description of the different parts of the work will now be given, taking up afterwards the manner and order in which they were executed. And first to speak of the spillway, which is shown in plan on Plate LIV, and in elevation on Plate LV. This important feature of the dam has a total length of lip of 152.56 ft., and the lip is 5 ft. below the lowest crest of the dam, shown to the right on Fig. 2, Plate LV. The numerous disasters which have occurred from spillways of insufficient capacity, abundantly prove the necessity of great care in fixing their dimensions. In the present case the problem was simplified by the fact that the spillway of the old distributing reservoir, a few miles further down the stream, furnished a basis for calculation. The writer was thus led to adopt the dimensions given above, which have proved to be ample. It will be noticed that on the northerly side—the left-hand side on Fig. 2, Plate LV—the top of the masonry center wall is 1 ft. higher, and the top of the earthen embankment 3½ ft. higher, than the top of the masonry on the southerly or right-hand side, as shown on the same figure. The object of this difference of level was, that if some unprecedented freshet should overpower the discharging capacity of the spillway, aided by the blow-off pipes hereafter to be mentioned, the overflow should take place over that portion of the dam which was of masonry rather than over the earthen embankment. Should such a case occur, the overflow would pass over the gate chamber wall on the right, and the whole length of the side wall along the Delaware, Lackawanna and Western track. This would, of

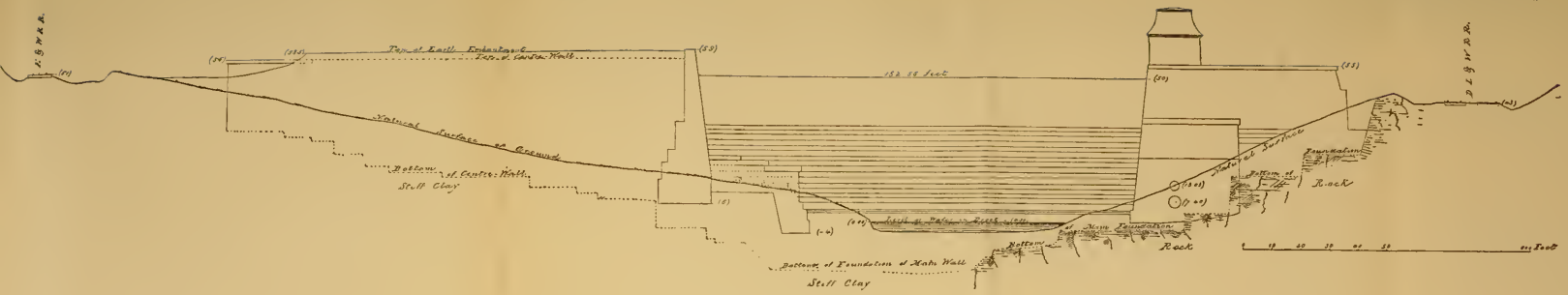


Fig. 2.

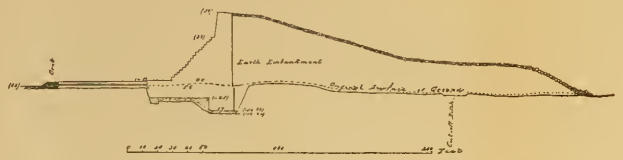


Fig. 3.

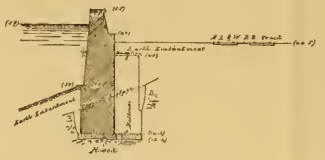


Fig. 5.

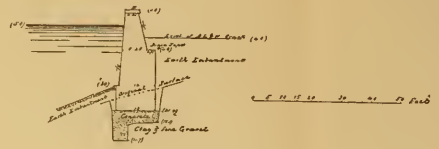


Fig. 4.

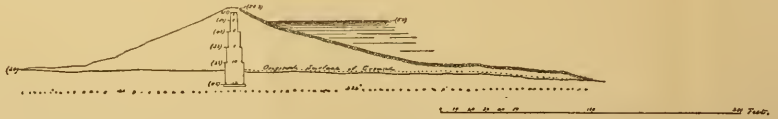


Fig. 5.

course, do great damage to the track, but would insure the more perishable portions of the dam against destruction, and compel a minor disaster to take place instead of a more general one.

A cross-section of the spillway and embankment is shown in Fig. 3, Plate LV, taken through a point where the embankment is the longest, on the line *A–B* of Plate LIV. It will be observed that the masonry is backed up to its full height by a heavy bank of earth. In other words, the inside embankment is continuous over the entire length of the dam, so that in one sense it is an earthen dam with masonry spillway and other adjuncts. The writer is strongly in favor of the earthen backing for all masonry dams. This feature will be referred to again.

This section (Fig. 3) shows the dam as built upon a foundation of stiff clay and fine sand. Where founded upon rock, the concrete was sometimes dispensed with, the surface irregularities being leveled up with spalls.

The sloping front of the spillway was stepped, rather than curved, or simply battered. This was cheaper than a cut stone curved face would have been, and, besides, this manner of handling the overflowing water is preferable to letting it attain a high velocity by sweeping over a free and unobstructed surface. In the writer's opinion it is better to act upon the contrary principle, namely, to destroy its horizontal velocity by a series of falls, by which means the water reaches the apron at the foot of the dam with but little momentum. Of course, either way, the same amount of water per second must finally pass through the channel below the dam, but the difference of level between the top and bottom of the spillway is, in the writer's opinion, better overcome in this manner, although it must be admitted that the question is an open one, on which it is hoped the views of other members may be given.

The construction of the apron is shown also in Fig. 3, Plate LV, and its plan on Plate LIV. This was one of the last pieces of work done, and during the time of construction of the spillway, and previous to its completion, it was repeatedly swept over by floods. The effect of these was to excavate, more or less, the bottom of the stream directly in front of the dam, but to a less extent than was anticipated. In constructing the apron, a timber crib filled with stones was placed at its lower limit. The bottom of the stream was leveled up with dry stone, the excavated portions being first filled up with small stones, and then

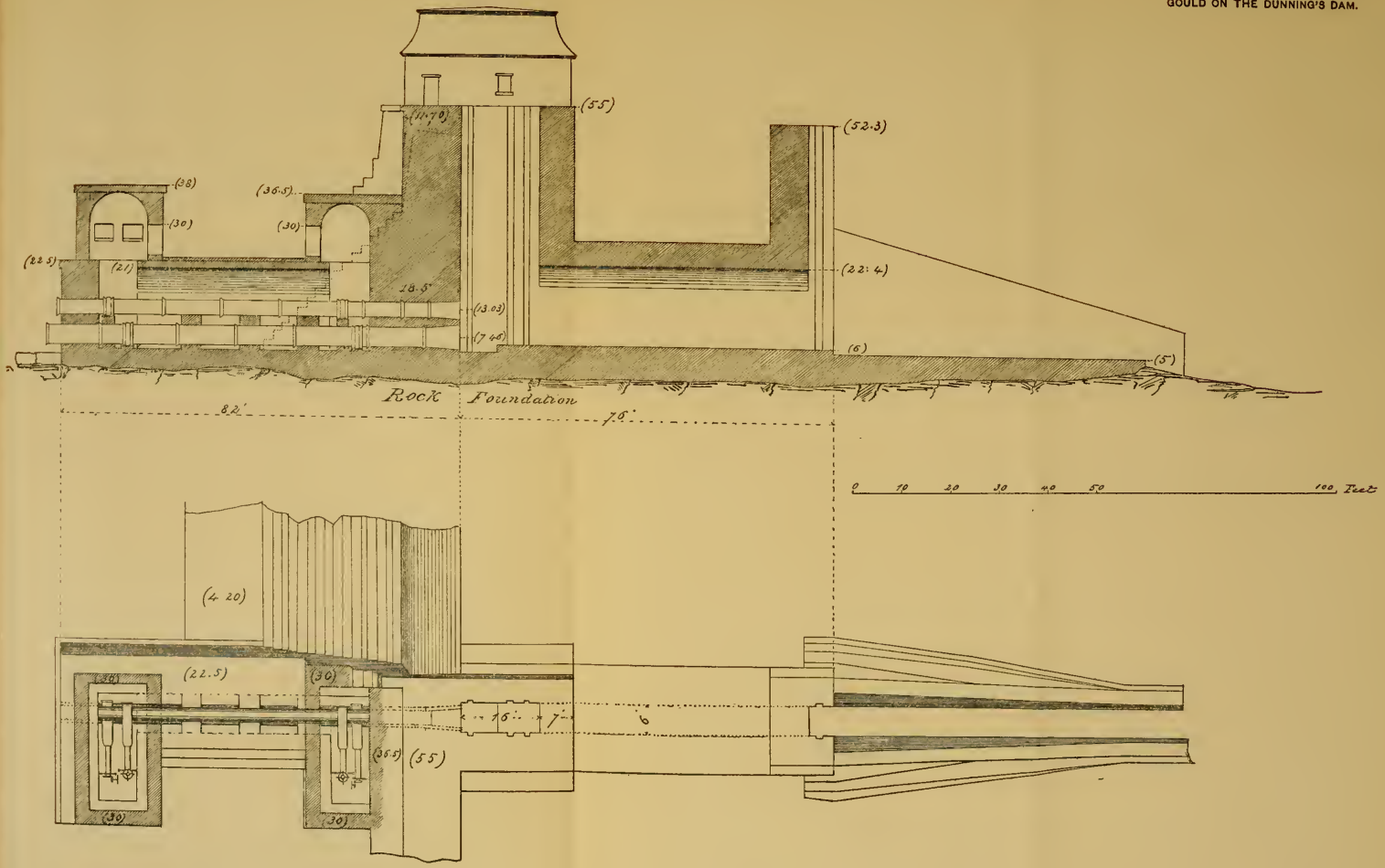
the largest obtainable placed as regularly as possible on the top. The joints of these were packed with spalls, and then a continuous bed of concrete, averaging about 1 ft. in thickness, spread over the dry stone. On the top of the concrete a stone masonry pavement was placed, consisting of heavy blocks bedded in cement mortar. Later on, some additional dry stone rip-rapping was placed below the crib, to protect it and regulate the channel below. The result of the whole has proved to be eminently successful in preventing wash.

The next most important feature of the dam is the gate chamber and its appurtenances. The writer gave this matter, as it merited, the deepest consideration, going over the drawings and modifying them repeatedly before evolving a design which seemed to him to be fully satisfactory.

This part of the work is shown on a small scale in plan, on Plate LIV, and in front elevation on Fig. 2, Plate LV, and in plan and bird's-eye, and in longitudinal section on Plate LVI.

In order to understand clearly this part of the work, it will be necessary to state the objects which it was sought to accomplish. In the first place, it was necessary to have some simple and easily handled means of drawing water from the reservoir when desired, and the means and appliances used must be, besides, not liable to get out of order, still less to break down. Moreover, they should be of capacity sufficient to appreciably relieve the reservoir in case of necessity, even to the extent of nearly or quite emptying it, at least in the dry season, and for this purpose the opening should be located as near as possible to the bottom of the reservoir. In the present case it was also desired to provide means to connect the city supply directly with this reservoir, so that the actual distributing reservoir could be cut off if desired.

The writer has long been convinced that the best and handiest way of drawing and shutting off water from a reservoir is by means of a cast-iron pipe, built into the masonry of the dam (or of the center wall, if it is an earthen dam), and controlled by two gates or stop-cocks, one placed as near to the dam as possible, and the other a certain distance further along. Accordingly there was built in, in this way, a 48-in. cast-iron pipe, as shown on Plate LVI, as low down as possible, and provided with two horizontal gates, of the New York City pattern. This pipe was supported in solid masonry blocks throughout its entire length, reaching from side to side of the pipe gallery, with holes in the


(55)
(11.70)
(52.3)
(38)
(36.5)
(30)
(30)
(22.5)
(21)
(22.4)
28.5'
(3.03)
(7.48)
(6)
(5)
Rock Foundation
82'
75'
0 10 20 30 40 50 100 Feet
(4.20)
(22.5)
(30)
(30)
16'
7'
6'
(36.5)
(55)
(30)
(30)

bottom, to drain off any water which might otherwise accumulate. Directly over this was a 36-in. pipe destined to be used as a main to the city, if desired. This pipe was also provided with two gates, same pattern and make, and was supported by the same blocks of masonry as the 48-in. pipe, these blocks being continued up to about the axis of the 36-in. pipe. In this way, the 48-in. pipe was, at the points of support, entirely circled with masonry, while the 36-in. was supported in a cradle, extending to half its height. Of the two gates on each pipe, the inner one is to be kept open, or partially open always, and the water turned on or off by means of the lower, or down-stream one. Then, should any accident occur to this latter, the upper one is closed, and the lower one can be got at for repairs. Directly over these gates, in the two gate chambers, wrought-iron eye-beams were built into the walls, so that in case of wishing to handle the gates at any time, blocks and falls could be rigged over them.

Although the two gates above mentioned furnish a pretty good security against accidents, it is necessary to have some additional means of shutting off the water, and of shutting it off in such a way as to permit access to the mouth of the discharge pipe when the reservoir is full. If this case should occur when it became necessary to get at the mouth of the pipe, without emptying the reservoir, it would be obviously necessary to construct some sort of a coffer-dam in front of it, or, as a makeshift, to send down a diver. It would, therefore, be better to construct a permanent coffer-dam at the start, making it a part of the structure, by building a sort of tower containing grooves into which stop plank could be dropped, shutting off the water in a manner which, though not absolutely perfect, has the advantage of being rude and simple, and therefore not liable to get out of order as sluice gates worked with a screw sometimes do.

Plate LVI shows such a tower containing two sets of grooves for stop-plank separated by a certain interval which can, if necessary, be packed so as to make the coffer-dam quite water-tight. There is also a third set of grooves intended for the reception of screens should the supply mains ever be connected with the 36-in. pipe.

As has been already stated, the whole of the inside face of the dam was provided with an earthen embankment, not only the northerly part, which consists of a masonry center wall, and an inside and outside bank of earth, but also the southerly half, where a purely masonry

dam was built, and then an embankment of earth added on the inside. There were two reasons for this. Had the inside embankment been confined to the northerly portion, a very heavy and expensive retaining wall projecting into the reservoir would have been needed, costing more than making the bank continuous. A second reason was the conviction, already mentioned, that such a backing is always an advantage, even to a masonry dam. It impedes leakage, and is equivalent to a deepening of the foundation on the water side. A dam built in this way may be regarded as an earthen dam in which the exterior slope of earth has been replaced by an equivalent mass of masonry applied to the front of the center wall. This is the form of dam of medium height which the writer would always recommend when a rock bottom can be found. If the foundation must be upon earth, he would hesitate to adopt it, for he would consider the extra concentration of weight on a smaller surface at the junction of the two different materials, masonry and earth, as disadvantageous, and, besides, would probably feel that the more extended earthen bank would be needed to smother down any percolations from under the center wall which might otherwise show in front of the dam.

The existence of this inside bank made it necessary to study how communication should be established between the water tower and the inside of the reservoir. Building the tower with three sides only, leaving the back open and building two retaining walls, to form an open passage into it, had been thought of. These walls would, however, be very expensive, as has been already intimated, and it was concluded, therefore, to construct an arched gallery running through the bank. It is interesting to note how, in designing, one idea runs into another, so it may be mentioned here that, while studying out the design for retaining or wing walls, the writer considered the possibility of greatly reducing their thickness, and at the same time getting the necessary strength, by throwing at intervals arched braces between them, so that they should be mutually sustaining by being thus connected. It was only a short step further to make these supports continuous, and this led naturally to an arched gallery, such as was actually built.

In order to make this part of the work as complete and efficient as possible, a small tower was also placed at the entrance to the gallery, provided with one set of grooves. In these grooves were placed frames

PLATE LVII.
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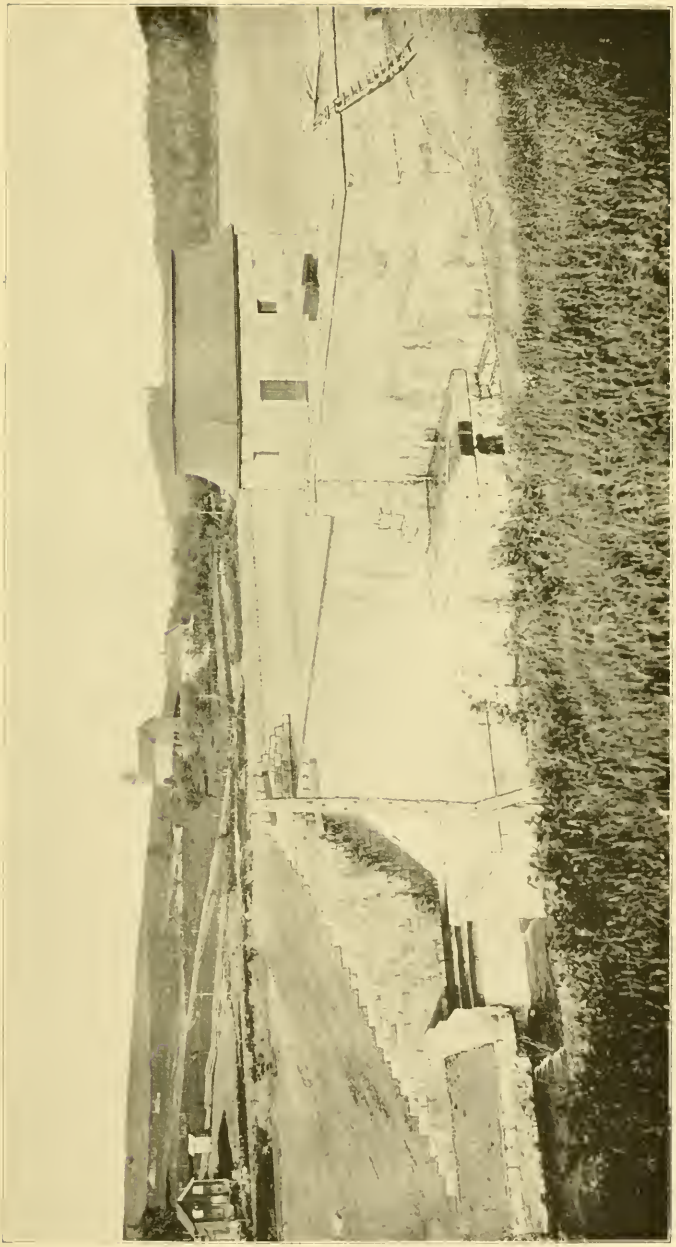
GOULD ON THE DUNNING'S DAM.



containing vertical iron bars, some 6 ins. apart, for the purpose of arresting any large floating objects which might otherwise get into the pipes when the water was drawn down. These grooves would also admit of stop-plank being placed in them, by means of which the entire gallery could be emptied of water and inspected while the reservoir was full.

Now, there is a point in regard to these features of the reservoir to which the writer would like to call attention, and that is the way in which they are grouped together. It will be perceived that the main water tower is placed directly against the dam which forms one of its sides, while the northerly side of the tower forms the jaw of the spillway on that side. The gate chamber is also placed in direct contact with the face of the dam, while its side forms the flanking wall of the spillway. In this way not only is material economized, but the structure greatly strengthened at this point by the mutual support of its several parts.

It may here be observed that it is an open question if it would not have been preferable to suppress the outside gallery connecting the two gate-houses, moving the lower one back to the upper and throwing them into one. There would have been some small saving of material, and the design would perhaps have been neater. On the other hand, by the present design, the lower gate is further removed from the dash and spray of the falling water, with perhaps some other advantages. Upon the whole, however, the writer is at present inclined to believe that it would have been a more workmanlike design to have brought both sets of gates under one roof.

Below the lower gate-house, the bank is protected against the wash of the discharge pipes by a heavy retaining wall, curved in plan, and a solid pavement laid in mortar receives the wash from the pipes. This wall and pavement are shown in plan on Plate LIV.

The part of the work which, perhaps, caused the greatest solicitude was the return wall along the Delaware, Lackawanna and Western track, destined to retain the water above the level of the same. The first 200 ft. or so of this wall stood on rock foundation, and, of course, gave rise to no anxiety. After that, however, it left the rocky projection already mentioned, and continued the rest of the way upon earth, mostly clay and fine gravel. The wall was built on the sloping bank lying between the railroad and the stream, in some cases

cutting the foot of the railroad embankment, and thereby giving a good deal of trouble to the contractors, to prevent bringing away the track. It was evident that no fears were to be entertained as to the resistance of the wall against water pressure when the reservoir was full, because it was backed up against the railroad embankment, and could not therefore be overturned nor moved outwardly. The danger to be apprehended was from its being thrown inwardly from the enormous earth pressure against it when the reservoir should be empty, more particularly as the sloping bank upon which it stood would in such case be greatly softened, if not absolutely saturated, from the recent presence of the water. Of course, danger from the softening of the ground on which it stood could be overcome by carrying the foundations down below the bed of the stream, but this would have led to such an enormous increase of expense that the idea was not even entertained. It may here be remarked that the problem was regarded as relieved of a great deal of its gravity by the fact that the possible destruction of the wall could only be looked for when the reservoir was empty; its failure, consequently, could not be accompanied by the awful disasters incident to the bursting of a dam. This was, at least, some comfort, but, even so, the problem remained a very impressive one. A wall was to be built, 1 200 ft. long, exposed for the greater part of its length to the pressure of earth filled in between it and the slope of a railroad embankment. This wall, being built parallel to the stream, naturally would cut off a great deal of the ground and surface water which would otherwise find its way to the lowest point of the valley, so that the bank would be always more or less waterlogged. Weepers were, of course, inadmissible, but a drain pipe was placed outside of the wall parallel to it, and between it and the railroad track, so as to intercept at least a portion of the water and conduct it off below the dam.

Fig. 5, Plate LV, shows two sections of this wall, one on rock and the other on earth foundation. It will be seen that the lower part of the wall is vertical on both sides up to elevation (30). At this height an inset was made, and on the water side the wall carried up with a batter of 1 in. to 1 ft. to elevation (54). The coping raises it to (55). The thickness at the top, directly under the coping, was 4.25 ft., and the batter on the side next the railroad 3 ins. to 1 ft. On the water side, wherever the offset at elevation (30) was above the level of the

PLATE LVIII.
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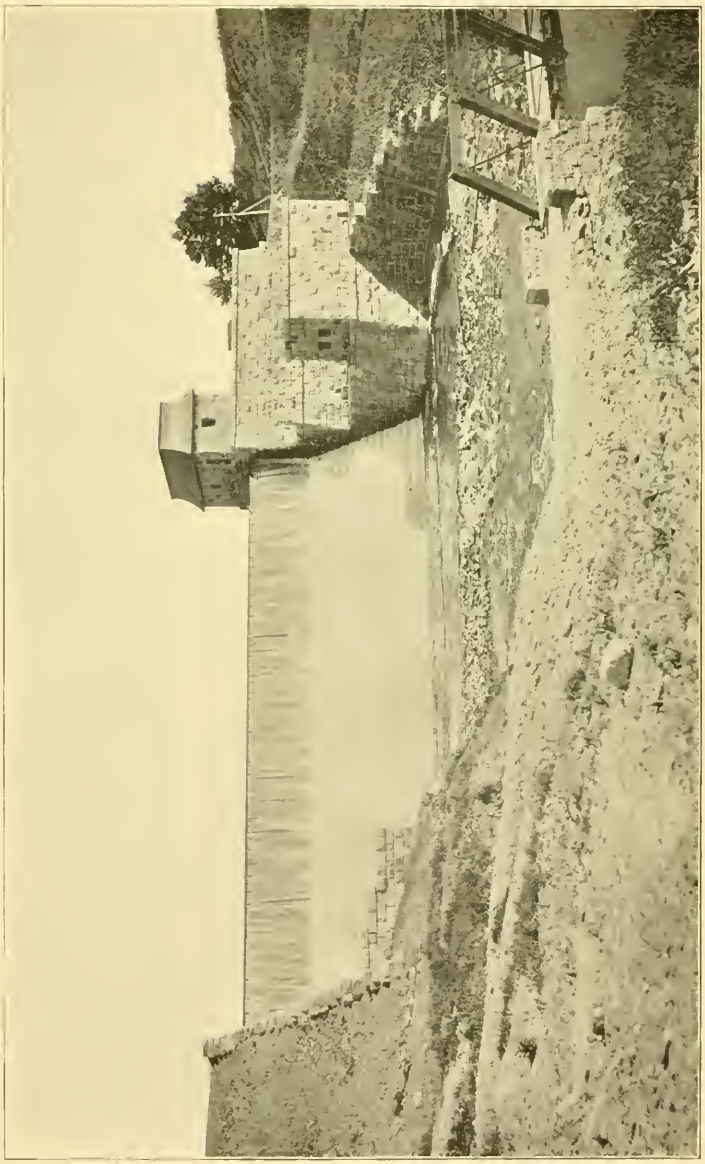
GOULD ON THE DUNNING'S DAM.



ground, an earthen embankment, rip-rapped, was placed against it at that height, so that the exposed surface of the masonry wall was never more than 25 ft. in height.

It will be readily understood that at times the excavation for this wall gave a good deal of trouble, owing to caving in of the bank. All contractors are apt to take risks in such work and try to get the pit taken out and the masonry built without timbering. In this way a great deal of the excavation has to be taken out twice. In order to economize concrete and to get on as fast as possible, the foundation pits, in earth, were not taken out to the full depth for the full width. The dangerous tendency being, as already mentioned, to overturn into the reservoir, the concrete was given its full depth only under the inside toe about which the wall would tend to turn, as shown in Fig. 5, Plate LV. In the first sections of the wall counter forts were placed at certain intervals, but, largely owing to the delay and labor of excavating for them, particularly when placed on the outside, they were finally done away with, and an additional thickness given to the wall instead.

The center wall calls for no particular mention. It is shown with the embankment in section on Fig. 6, Plate LV. The flat prolongation of the inside embankment shows when the "temporary dam," to be mentioned hereafter, and other provisional filling were incorporated into the permanent work.

As has already been mentioned, the southerly side of the spillway is guarded by the gate chambers and other accessories. On the northerly side it is limited and the water confined by a heavy wing wall, which forms the retaining wall of the exterior earth embankment on that side. It will be remembered that the rock does not extend across the brook, so that this wall and a great part of the spillway rest upon an earthen foundation. Great care was therefore necessary to secure and protect all this part of the work from being undermined. To carry the foundation of the wing wall down below the bed of the stream would have been very expensive; not to do so, and to leave its foot unprotected, would be very dangerous. Accordingly, after going down a certain distance with the foundation, a second or "bench" wall was placed some 25 ft. in front of it, going a little below the bed of the stream, with its top higher than the bottom of the main wall. The intervening space was concreted and paved with heavy blocks of cut

stone, forming a platform over which the water coming from this end of the spillway could wash with safety. This arrangement is shown in Plate LIV, and Fig. 2, Plate LV.

In dam building, the proper order in which to execute the work is always to thoroughly clear and grub the area to be covered by the embankment (particularly the interior one) before any other work is commenced. This being done, all excavated material, when suitable, can be at once deposited in the bank, and just so much work done, once for all, with the advantage to the contractor of its being paid for twice, once as excavation and once as embankment. After this, everything connected with the discharge pipes and blow-off culvert should be got in, because, by choosing a time of drought, it will be frequently possible to divert the entire flow of the stream through these openings, and thus solve the otherwise always perplexing problem of how to get rid of the water when "closing the gap."

In the present case, the first of these operations was only partially carried out, and consequently considerable extra trouble and expense was incurred by the contractors.

In regard to the second point, that of building the discharge pipes, etc., first, the contractors considered it more expedient to commence work on the opposite or north side of the brook, by coffer-damming about half way across the stream, inclosing an area of about 80 x 40 ft. This coffer-dam unfortunately stopped just short of where rock was found on the south side. It would have been a great advantage if it had been extended a little further on, so that the masonry within it could have been at once bonded in with the rock, but the precise position of the rock was not known at the time, so the dimensions of the coffer-dam were largely determined by guess.

The coffer-dam consisted of bents 4 ft. apart, of 6 x 4-in. stuff, sheathed with 2-in. plank. The bents were 4 ft. wide, and the interior space filled in with clay. This coffer-dam was very nearly perfectly tight, and work was carried on very satisfactorily within it.

As regards the nature of the bottom of this excavation, which was destined to contain that part of the spillway and apron, the writer quotes as follows from his journal, September 8th, 1887:

"Have got down to a stratum of quicksand, fine and coarse gravel, which I consider favorable to start the work on, the only objectionable feature being the stones, cobble and gravel. These, however, seem to

be encased in a matrix of fine sand and clay, and the whole forms, I think, a satisfactory and impermeable bottom."

Also the following note in the next day's journal entry:

"Bottom looked satisfactory—fine sand and gravel, quicksand and cobblestones; hard, compact, inelastic—a natural concrete in fact. Am convinced it will make a good foundation, at the depth at which we find it. A bar cannot be forced, by working or driving, more than a foot or so into it. No spouting springs when surface is pierced."

The rock on the south side lay in large flag-like slabs, from 1 to 2 ft. thick, dipping slightly to the north and west, with their partings and beds filled with compact clay. In cutting into this rock, for an excavation of certain width, a great deal of it would be loosened outside of the neat lines, so that much more than was desired would have to be taken away. It was found also impossible to get down to anything more compact and less fissured in its structure, for the entire formation was of the same character. Generally speaking, therefore, when enough of the surface rock had been removed to form a clean face, these large slabs were built upon just as they were, all irregularities being carefully packed with spalls, and care taken to disturb them as little as possible on their natural beds. In working in this rock, powder was very sparingly used; indeed its use was not generally allowed at all, owing to its shattering and dislocating effect.

Work was commenced about August 1st, 1887, and closed for the season December 1st of same year. By that time the foundations were in continuously across the stream.

Work was resumed April 23d, 1888, and in August of same year a "temporary" (so-called) earthen dam was built, to divert the water through the pipes, which by this time were set with their gates. This dam was allowed to form part of the permanent embankment. This process of diverting the water presented great difficulties and many vexatious delays, as the dams put up for the purpose were repeatedly breached. His notes are somewhat scanty in respect to this detail, but the writer thinks that the breach was finally closed by a dry stone wall, through which the water could freely pass while being built. When this wall was finished the water was excluded by placing brush, etc., against it on the inside, and dumping earth behind it, until at last it became tight. For this purpose sand and fine gravel again proved their immense superiority over clay for forming a water-tight

bank. By October 1st the dam was practically tight, and the whole flow of the stream passed through the pipes.

Work on the main dam was stopped for the season November 14th, 1888. A gap was left about 90 ft. long, at elevation of about (27) to provide for freshets. Work was continued on the Delaware, Lackawanna and Western wall till December 10th, when all operations were closed for the season, everything being left in good shape and prepared for any freshet which might occur, and only just in time, for on December 18th, 1888, a heavy freshet did actually take place, the water rising to about elevation (29), sweeping over the unfinished work, gorging both the 48-in. and 36-in. pipes, besides running through the gap in a sheet of water 90 ft. long and 2 ft. deep. The writer estimated the flow to be at the rate of about 1 000 cu. ft. per second, the drainage area being a little over 36 sq. miles. No damage whatever was done to the work.

Work was resumed April 9th, 1889. On the first of June of this year came the awful tidings of the Johnstown disaster, which naturally turned public thought to the safety of the Dunning's dam and reservoir, which was to be of about the same capacity as that at Johnstown, and occupying about the same relative position in regard to the town and steel works. No apprehension was felt by Mr. Scranton, or the writer; but the managers of the Lackawanna Iron and Steel Company requested permission to have the work inspected by experts, and on June 18th, 1889, George S. Greene, Past President M. Am. Soc. C. E., and Charles Macdonald, M. Am. Soc. C. E., inspected it, returning a reassuring report to the company.

The work this season was largely concentrated on the two side dams, one along the Delaware, Lackawanna and Western, and the other along the Erie and Wyoming tracks. The latter is shown in plan in Plate LIV, and in section in Fig. 4, Plate LV. Of these two walls, as already stated, the first was by far the most important. The foundations for this wall were nearly everywhere satisfactory. In almost all cases a pick was needed for each shovel. It may be here stated that this immense wall was throughout a satisfactory piece of work. In only one point was there any noticeable imperfection. This consisted in a small crack in the wall, which developed after it was built and pointed, at about 460 ft. from the angle with the main dam. The opening was widest at top. When first perceived it was about $\frac{1}{8}$ in. in width at the top, running out to nearly nothing further down. Every effort was

made to close this crack, both by pointing it up on the inside when the water in the reservoir permitted, and by dumping sand, cement, sawdust, manure, etc., in front of it, when the reservoir was full, in order that these substances might be sucked into it, with the water which leaked through. It still remained, however, although with time the slight consequent leakage has diminished. The writer has never been able to satisfactorily account for this crack, which did not appear to be due to settlement. He is inclined to believe that it may have been owing to contraction. The wall is a very long one, about 1 200 ft., its length being, however, broken by an offset, and was built very carefully and very compactly, so that it contained no play within itself for contraction. Indeed, if we admit the possibility of expansion and contraction in stone masonry, it is evident that the closer and better built the wall is, the more liable it must be to crack at some point from this cause. The writer would be glad to know if any one has had occasion to observe similar checks in extensive walls upon the construction of which no pains have been spared.

When the reservoir was first filled, considerable leakage was perceptible coming through the wall of the upper gate chamber. It was found that owing to some oversight, the inside of the tower had not been thoroughly raked and pointed. Hay seed, sawdust, cement, etc., were thrown into the tower, and the leakage finally almost or wholly overcome. At present the writer is inclined to doubt if it is wise, in the long run, to immediately rake and point the joints of hydraulic masonry, still less to cover it with plastering, and believes it would be better to turn on the water first, and see how water-tight the wall is of itself, and do the pointing and plastering afterwards. Leaks suppressed by plastering will, of course, break out when the plastering begins to come away (as it surely will sooner or later), and then fears would be excited for the safety of the work.

After the completion of the work, the reservoir was allowed to fill slowly, the rise of the water being regulated by the discharge pipes. On November 15th, 1889, the water was allowed to run over the spillway to the depth of 0.4 ft.

The final estimate was handed in early in February, 1890, as shown on page 404.

A few words regarding the manner in which each of the principal classes of work mentioned in the table was executed may be of interest.

FINAL ESTIMATE OF DUNNING'S DAM, FEBRUARY, 1890.

CLASS OF WORK.	QUANTITIES.	PRICE.	AMOUNT.
	Acres.		
Clearing reservoir site	193.87	$40 00	$7 754 80
	Cu. Yds.		
Rock excavation	6 795.43	1 00	6 795 43
Earth excavation	19 337.70	0 35	6 768 20
Earth embankment	74 804.90	0 35	26 181 72
Cut stone masonry, natural cement	81.20	11 00	893 20
Rubble masonry, natural cement	4 310.62	6 25	26 941 37
Concrete masonry, natural cement	100.10	5 00	500 50
Covering stone, natural cement	84.52	6 25	528 25
Cut stone masonry, Portland cement	858.53	11 50	9 873 09
Rubble masonry, Portland cement	27 219.25	7 00	190 534 75
Concrete masonry, Portland cement	2 742.12	6 00	16 452 72
Brick masonry, Portland cement	148.10	11 00	1 629 10
Covering stone, Portland cement	225.28	7 00	1 576 96
Dry stone wall	1 452.16	3 00	4 356 48
Rip-rap	7 761.65	1 50	11 642 48
			$312 429 05

In clearing the reservoir site, all trees and stumps were cut as nearly as possible level with the ground. That portion of the site which was to be covered by the embankment was grubbed and the sods removed, and, generally speaking, ploughed up before placing the embankment upon it, so as to bond in well with the material forming the embankment.

The embankment was placed, as far as possible, in layers. The material was mostly taken from inside the reservoir, being taken out by a steam shovel, and brought to the foot of the embankment in cars. It was then scraped into place by scrapers, drawn by two horses each. A portion was also placed by wagons having movable bottom boards. It was kept sprinkled while being put in, and the travel of the men, teams and scrapers was sufficient to thoroughly compact it. The material was mostly clay and gravelly loam.

The stone used was mostly the conglomerate found under the coal beds. It was in every respect an admirable material. As a great deal of the work was very thick and massive, some very large stones were used, and, generally speaking, although in drawing up the specifications, the right was reserved to reject all stones over a certain size, considerable latitude was allowed in this respect, only a perfect bedding and jointing of all stones with compact mortar was insisted upon. The masons who executed this work had had a previous train-

ing upon the Oak run dam, and the foremen, as well as the inspector, had by this time thoroughly learned what the writer's requirements for hydraulic masonry were. On commencing work on the Oak run dam stones were constantly raised, after being bedded, and examined, to see that all portions of their beds had come in close contact with the mortar. In working on a thick wall, mortar was thrown in very liberally with the shovel, and all beds kept swimming. When operating this way, there need be no waste of mortar, for the surplus for one stone goes towards the bedding of the next, provided there is a strong gang of masons and a smart foreman to keep the derricks constantly on the swing. On one occasion one foreman, with eight masons and about nine helpers, laid nearly 500 cu. yds. of rubble in 76 hours. This was done with a double drum steam derrick; and, again, another foreman, with seven masons (and probably about eight or nine helpers), laid about 375 cu. yds. in seven days. This represents very rapid work, when the exactions of the engineer and the strictness of the inspection are taken into account.

Concrete was made of hand broken stone, and was hand mixed. The specifications called for proportions of 1, 2 and 3. It was found, however, that this produced an entirely too "fat" mixture, and 1, 2 and 5 was allowed, with good results. When there was running water to contend with, the richer mixture was used, to compensate for wash.

The writer found here, as elsewhere, that 2 cu. yds. of concrete in place, per man per day, counting the entire gang employed, was as much as could be done. The greatest care was exercised in mixing the concrete. A thorough incorporation of ingredients was insisted upon, with thorough tamping. The same care was bestowed upon the mixing of the mortar. No number of turnings was prescribed, but the mixture of sand and cement must be brought to a uniform color before adding the water. Also, a proper consistency and degree of moisture was insisted upon. The proportions were 1 of cement and 2 of sand, when using natural and American Portland cements. When using imported Portland of accepted brands, 1 of cement and 4 of sand was allowed to replace natural cement mortar, and 1 of cement and 3 of sand, to replace American Portland. The testing of the cements the writer attended to personally. When the inspector was not otherwise employed, he also was given tests to make.

Very little masonry or earth work was done on this dam in freezing

weather. While it was in construction, however, the writer was also building another much smaller dam upon another stream—the Stafford Meadow Brook—for the same company. This work had to be begun at once, and was, therefore, carried on during the winter of 1887–88. It was built with American Portland, and a steam boiler, belonging to a pump, was employed for heating the water used in making the mortar, and in steaming the wall and each stone laid in it. In this way every stone was bedded unfrozen. It is probable that the wall froze up each day, and remained frozen till the following spring. It was then examined, found to be all right, and the joints raked out and pointed. What really went on inside of that wall, the writer does not know, and had serious doubts when building it as to whether the mortar would set up after it thawed out, but whatever the process was that went on during that winter and the succeeding spring, the result was perfectly satisfactory.

The writer cannot close this paper without expressing his high appreciation of the manner and spirit in which the work was executed by the contractors, Messrs. Burke Brothers, of Scranton. All the require, ments were faithfully carried out, and they made it a matter of pride to turn out a first-class structure. His thanks are due to his assistant, W. M. Marple, M. Am. Soc. C. E., who had entire charge of laying out the work, which, as will be seen by the drawings, was in many places of a complicated and intricate character. Everything confided to his care was well and accurately done. Mr. J. H. Armstrong was constantly on the work as inspector, going on and off with the whistle, the same as the contractor's foremen. While carrying out instructions to the letter, with skill and intelligence, he had the tact never to antagonize the contractors. It is a pleasure to the writer to bear witness that the eminently successful results achieved in the building of the Dunning's Dam were largely due to the hearty co-operation and good faith of the contractors, and the zeal and fidelity of his assistants.

NOTE.—In all the accompanying drawings, figures inclosed in brackets indicate elevations above or below datum. This is in accordance with the excellent practice of the military engineers in designating "References."

DISCUSSION.

William E. Worthen, Past President Am. Soc. C. E.—The hearting of the dam which I constructed across the Mohawk, at Cohoes, in 1865, was intended to have a portion of it of large stone, but soon after starting the work it was thought better to make it of quarried stone of sizes that could be readily laid by hand. The work could be made perfectly solid in this way without any chance of voids; the stone could be got more conveniently, and the traveling cranes could be used entirely for the ashlar, with the result that the dam was completed in one season, from the middle of July to about the first day of October, while it was the first intention to have occupied two years.

The dam was of stone, about 1 400 ft. long, an overfall to an old cob dam. The caps were 10 ft. long, some 2 to 3 ft. wide, well bedded in

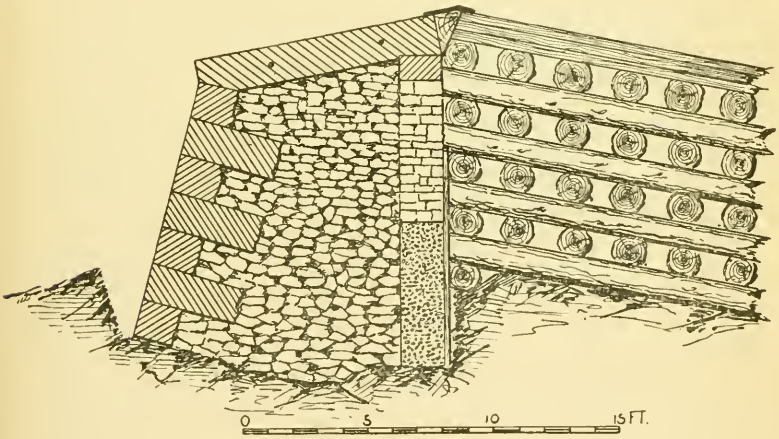


Fig. 1.

cement mortar, dowelled together by galvanized iron dowels; the lateral joint to the depth of 6 ins. was run in sulphur. There was no trouble from expansion, although it was exposed to all extremes of weather, being at times bare, both summer and winter. This sulphur joint kept good till about three years ago when it was re-run as before.

Fig. 1 is a section of the dam in which it will be seen that it supplements an old cob dam, which had settled very much, and of which the overflow had cut deeply into the rock base endangering its stability.

The rock-bed was Hudson River shale to an unknown depth; a shaft was afterwards sunk near the Harmony Mills to more than 1 800 ft. in depth in this strata, and without securing the supply of water for a paper mill for which it was intended.

Plate LIX is a photograph of the dam while under construction, which, with the section, is sufficiently illustrative of the work. At the commencement a board sheathing was nailed to the timbers of the old dam, and made as tight as possible laterally, and at the bottom, on the down-stream side, and at about 20 ins. from the sheathing a close sheet piling was set; care was taken to make the bottom joint tight by what might be termed sausages of dry cement mortar in muslin skins. The channel thus formed was cut into small sections by boards and filled with concrete. The concrete was made in such quantities that the cut-off section could be filled promptly from one batch. A length for dam below the concrete was cut off by piling, mud dams, or the rock itself, and the space was freed from water and cleaned, and then the laying of the stone commenced. As the work progressed the sheet piling was gradually removed and the hearting was connected with the concrete.

The ashlar was limestone, from Amsterdam, delivered by the Erie Canal, close to the work, and carted down to the river-bed to the travelers. When it was decided to finish the dam in one season, stone of like quality was obtained on the Champlain Canal and delivered at the same place.

The water of the river above the dam was kept off the work by wooden bulkheads or flash-boards, in height and of lengths sufficient to keep the water off the work in progress. Behind this bulkhead the small hearting stock was deposited by boats from a quarry up the river. The space at the top, between the cob and masonry dam, was filled in with a string course of timber, and the upper joints covered by iron plate.

W. R. Hutton, M. Am Soc. C. E.—The conspicuous feature in this dam is the abrupt change in the character of the material upon which it rests, one-half its length being upon rock, the other upon earth, a stiff clay and sand. This construction was a bold departure from recognized principles, and is not to be rashly followed. Its success appears to be due to the section of the masonry and to the embankment on its upper side, the resultant of all the forces acting upon the foundation, passes nearly or quite through the center of the base, giving moderate pressures (about 4 000 lbs. per square foot), uniformly distributed. The building upon such a base seems to have been unavoidable, hemmed in as the reservoir was by a railway on either side, which excluded the alternative of a spillway, excavated in the rock or located entirely upon it.

In the matter of an earth backing to a masonry dam a certain distinction must be made. As the author himself says, this is an earthen dam with a waste weir or spillway of masonry, a construction clearly indicated by the circumstances of foundati on and relatively small height. This mixed method can rarely be applied with economy

PLATE LIX.
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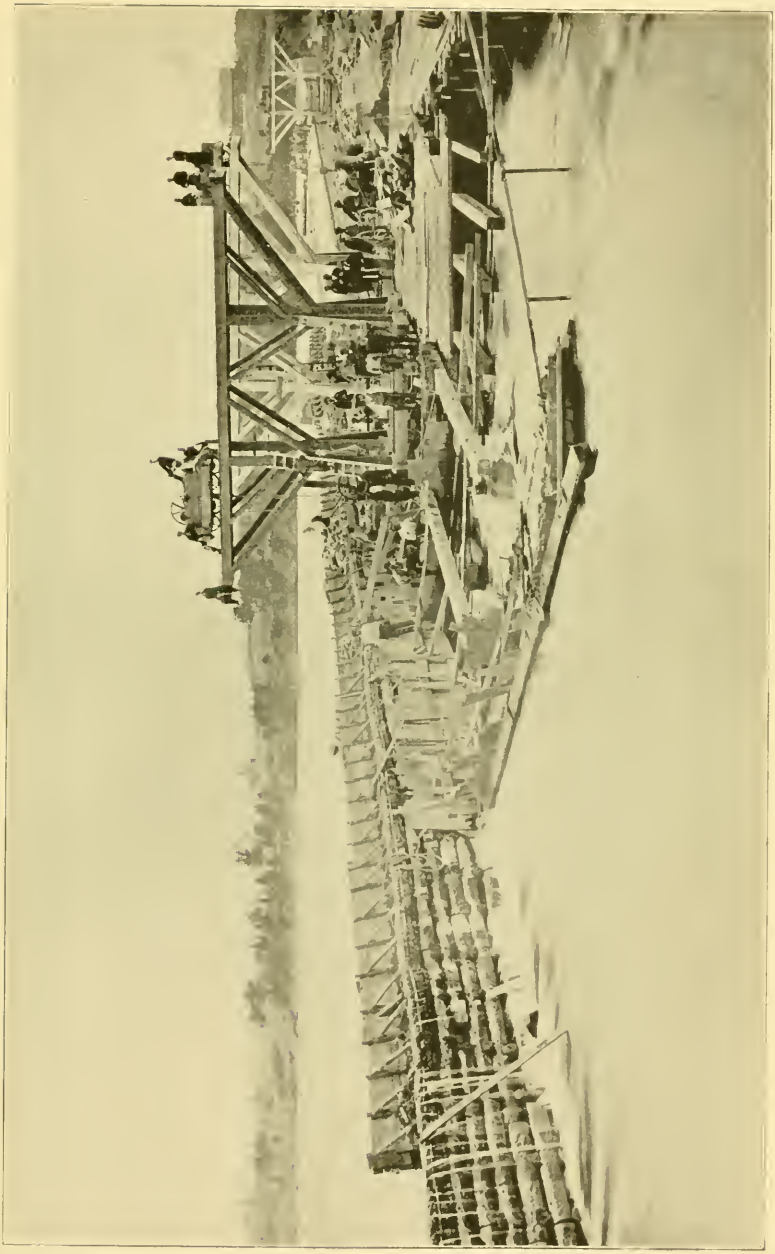
VOL. XXXII, No. 737.
WORTHEN ON COHOES DAM.



and safety to dams of much greater heights than the one under discussion. One hundred feet is probably the limit of height for earth dams. To "high" dams—those over 100 ft. in height—the addition of an embankment on the interior of the reservoir would mean greatly increased expense beyond any compensating advantages.

The sloping front of the waste weir is built in low steps, by which the *vis viva* of the falling water is considerably diminished. This result is highly desirable, and the method has been successfully practiced with crib dams, which, being built of long and tenacious material, are not so much dependent upon superincumbent weight as in the case of a masonry face. In crib dams, however, the steps are long, 6 to 12 ft., and the height much less than the length. They are, in fact, so many aprons upon which the total fall of the water is distributed. In masonry dams with vertical faces and exposed to heavy overflows, it has been deemed unwise to permit any projection on the face. The case here is entirely different, and the author states that the water at the foot of the dam in moderate floods is quite smooth and free from destructive eddies.

The failure of the retaining walls along the railways could occur only by reason of the softening of the ground on which they stand. A broader footing on the inside of the wall would have been an additional protection against overturning.

In the matter of leakage through masonry due to neglect to rake out and point the joints, it has been shown by experiment that cement mortar is not in itself impermeable. Its troweled or burnished surface alone will resist percolation. If the joints are sufficiently regular, they may be rubbed down or burnished when laid. In a wall of rough rubble, the mere raking out the irregular spaces between the stones and filling them with fresh mortar will not do much good, and the chances are that the filling will come out. In the experience of the writer, well-troweled plastering of cement mortar has been efficient and has stood well where not exposed to freezing.

Temperature Cracks in the Long Walls.—There is no doubt that very long concrete walls do crack under variations of temperature. The experience of the Dock Department of New York leads to the making of a transverse joint once in every 150 to 200 ft. of wall. In *Proceedings*, Institution Civil Engineers, for June, 1894, is a description of a service reservoir at Colombo, with concrete walls about 40 ft. high, which cracked under temperature strains, and was only rendered stable by covering it with an embankment of earth.

The author suggests that the two gate chambers might with advantage have been replaced by one. It certainly could have been done at less cost and with greater simplicity. The most simple arrangement is that of a gate-house at the foot of the inner slope of the embankment, closed with stop planks, and having gates at the end of the pipes,

operated from the floor of the gate-house. If more detailed regulation is necessary, a stop-cock vault at the outer base of the embankment will be of easy access. Some of the French engineers have recently invented this arrangement and consider it one of the most important improvements of the day, partly by reason of its simplicity, partly because it renders unnecessary any masonry construction in the body of the embankment, which prevents the uniform compacting of the material. The form is not rare or new in this country. A gallery to carry the pipes under the embankment would seem to be unnecessary. They may be bedded in a mass of concrete, properly formed, with cross-walls. In a gallery it would be preferable to give a continuous support to the pipes, but quite unnecessary to cover them with masonry.

W. H. Baldwin, M. Am. Soc. C. E.—I think, that as this is a dam calculated to resist a high velocity and strain of water behind it, it is hardly to be compared with the reservoir I am engaged in building, which is merely a distributing reservoir of about 50 000 000 galls. for the water supply of the City of Yonkers, N. Y., and has no overflow.

I have been interested in what the writer has said about a masonry dam. I am engaged in building a partition wall which is intended to divide the reservoir into two compartments. As the water would frequently be at different levels on opposite sides of this wall, there is some solicitude about leakage and percolation; I am awaiting developments in that line. With that exception, I do not think there is any parallelism between the work under my charge at the present time and the work described. Fortunately, in my work all the foundations are on solid rock, so we anticipate no trouble in the way of undermining.

James Owen, M. Am. Soc. C. E.—The only point that occurs to me is as to the imperviousness of the soil. I presume the result has shown that it was satisfactory in this case.

Also, there is the contingency of the water finding its way through the seams of the rock on one side. In one case where I put up a dam I had great trouble in getting it water-tight on the rock side of the valley. I could keep it tight on the earth side, and I tried coating the rock with cement, but did not find it very satisfactory.

I had one rather curious experience as to porosity of soil. An owner was paid compensation for his land and also for a dam and for his original water right. An impounding dam was built near the same spot, and compensation was afterwards paid for drowning his land below by the water leaking through the natural soil below and around the dam.

About 17 years ago I built a dam of almost pure sand, about 12 ft. high. I found after a period of two years it became absolutely tight, and is still perfectly impervious to water.

KENNETH ALLEN, M. Am. Soc. C. E.—The question of the relative merits of the various profiles for the face of weirs has not, it is thought, been given the same attention as the cross-section required to withstand the static pressures acting on a dam. This is, no doubt, in part due to the fact that the stability of a dam is of the first importance; that this stability is subject to a fairly close approximation by calculation, and that, by this means, a certain economy in construction will result.

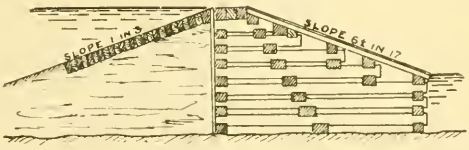
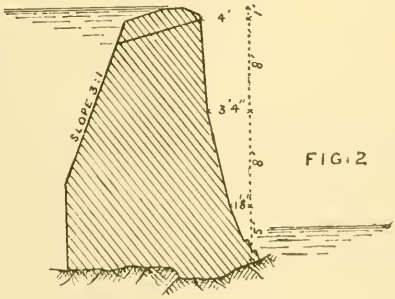


FIG. 1

Timber Crib Dam of the Schuylkill Navigation Company.

In providing for the overflow of dams, on the other hand, more factors have to be taken into consideration, and more liberty is given to the engineer in the introduction of special designs to meet the peculiar local conditions.

Mr. Gould has shown that, with good workmanship, a spillway 40 or 50 ft. in height, discharging water several feet in depth, may be safely built with a stepped face—a profile easy of construction and one which will destroy much of the scouring tendency of the water on leaving it.

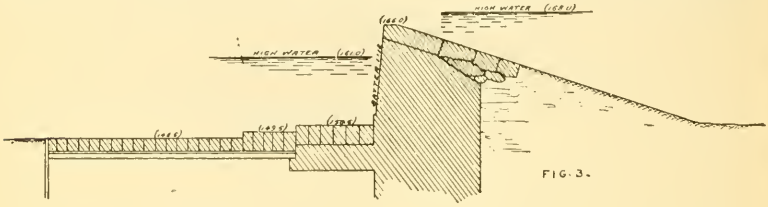


Macopsin Intake Dam, Newark, N. J., Water Supply.

The impact of a large volume of water falling from the crest of a dam is a powerful agent of destruction, as is made evident by the large number of failures from this cause. The undermining of the dams, or their aprons, at Housatonic, Conn.; Mechanicsville, N. Y.; Holyoke, Mass.; at the Falls of St. Anthony at Minneapolis, and of the dams built by the State of Ohio along the Muskingum River in that State are a few examples of the power of erosion from the overflow of dams, even where the river-bed is of rock.

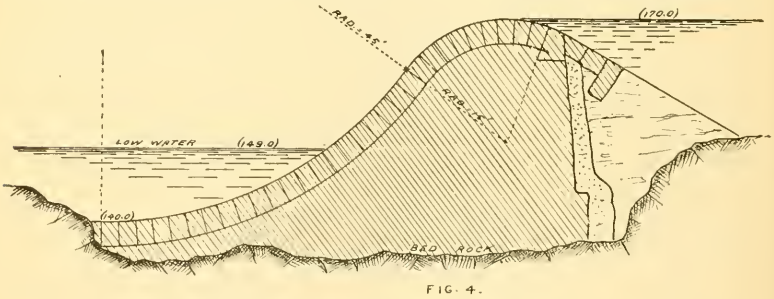
A further objection to the free fall of a large volume of water obtains when periodic vibrations are set up, causing sympathetic vibrations in neighboring buildings, windows, etc. This was sometimes the case with the old Holyoke Dam, and has been observed elsewhere, so that it has sometimes been necessary to draw off the water through the waste gates.

The means taken to prevent the destruction or undermining of spillways vary, depending on the height of the free fall, the depths on the



Dam No. 2.—Sudbury Supply for Boston, Mass.

crest and in the stream below during floods, the presence of floating ice or logs at such times, the character of the bed of the stream and of the masonry composing the face of the spillways. Broadly speaking, there are two ways of accomplishing this: first, by consuming a portion of the *vis viva* of the water through the formation of eddies and other internal motions, and, secondly, by so guiding the falling mass that on reaching the stream bed its motion will be approximately parallel thereto, reducing its scouring action to a minimum.



Lock Raven Dam.—Gunpowder Supply for Baltimore, Md.

This latter method is employed with success in the long, sloping aprons of crib dams of moderate height where a horizontal apron or steps would be subject to injurious impact from ice or logs, or where the fall at the lower end would produce dangerous scour (Fig. 1). It is also employed in masonry dams having a curved profile (Fig. 4); but the increased cost of dressing the stones or the greater quantity of masonry required often prohibits the use of this form. The Vyrnwy Dam for the Liverpool water supply is a good example of this class.

Most masonry dams are built so that the force of the falling water is exerted either directly on the rock bottom of the stream (Fig. 2), on an apron of heavy masonry at the level of the stream bed (Fig. 3), on a series of steps, as in the Dunning's Dam, or on a water cushion of considerable depth below the crest (Fig. 5). To obtain the necessary depth a subsidiary dam below the main structure may be necessary.

The writer would hesitate to suggest any rules to govern the design of a structure where so much depends on the special conditions existing in each case, but from a general consideration of dams, admittedly

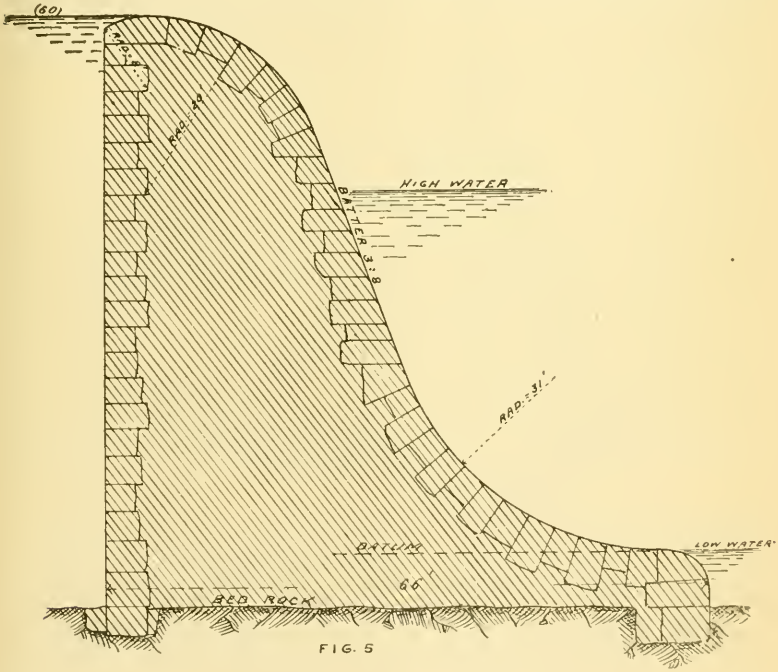


FIG. 5

Colorado River Dam at Austin, Texas.

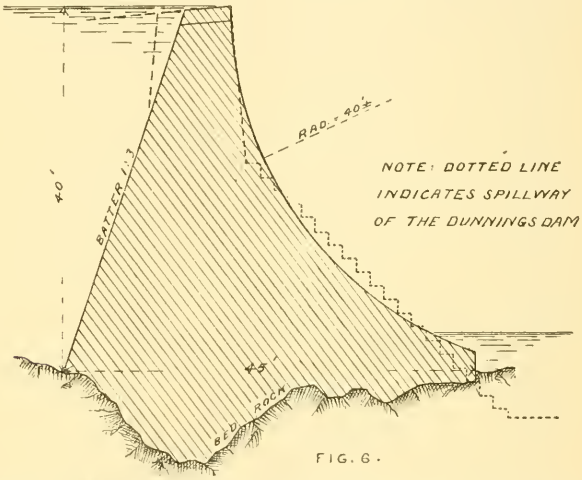
excellent of their kind, he ventures to draw the following general conclusions:

First.—Where the free fall is not great, say, under 20 ft., an apron will usually be found advisable, unless the stream-bed is of solid rock. When built of crib-work, this apron should have a slope down stream (Fig. 1), but if of masonry it may be horizontal or stepped. A fill of massive boulders below the crest, that is prevented from being washed down stream by a low retaining wall at its lower side, may be used in some cases as a substitute for an apron, as in the Anicut Dam recently built in India.

Second.—For higher dams the fall may be broken by steps or by a water-cushion.

Where steps are used and flood volumes are large, the character of the work should be unusually good, and, with high dams, it would probably be well to give the lower steps an outward slope, as suggested by Rankine, in order to lessen the shock of impact and the dash of water back against the face of the dam.

Third.—In the case of very high dams a saving will be effected by depending largely on a water-cushion. The use of steps to effectually break the fall of a thick sheet from a dam 66 or 80 ft. in height would necessitate an excess of masonry, and unless there were a good depth



North Adams, Mass., Dam.—North Branch of Hoosick River and Dunning's Dam.

of water to receive it, there would, in many cases, be danger of scour.*

Moreover, an attempt to guide the falling sheet by a curved face, as in the Vyrnwy Dam, results in a very heavy section where depths on the crest are great, and, unless founded on rock, will require a wide apron to prevent scour. Where the sheet of water is never very thick, however, a section similar to that of the North Adams Dam (Fig. 6) may be adopted. In many instances a combination of the types indicated will, of course, be best.

Local conditions vary, so that no inflexible rules can be laid down, but the above conclusions are supposed to be correct.

* Some interesting examples of subsidiary dams for the purpose of providing a suitable water-cushion are those for the Pick-Up weir at Vir, India, and for the Turlock and Folsom canal weirs in California—all of them works of considerable magnitude—described by H. M. Wilson, M. Am. Soc. C. E., in the *Transactions*, Am. Soc. C. E., Vol. XXIII, page 217, and Vol. XXV, page 161.

One other point is suggested by Mr. Gould's paper. Is it always safe to assume that the earth fill back of a dam relieves the wall of a portion of the pressure? It undoubtedly does so under favorable conditions, but is it safe to assume this in practice in our calculations? Considering the mass saturated to a semi-fluid condition, the small angle of repose will surely cause a greater pressure than that of water alone.

The question is an interesting and very practical one, which has apparently never been sufficiently settled to result in a uniform practice.

Fosier Crowell, M. Am. Soc. C. E.—The point the author has touched on, of carrying his work over from a rock foundation to the earth, is one which comes up, not only in dams, but often in other structures. Some little experience I have had in that direction teaches me to think that, if we leave out of consideration the question of keeping the lower part of the foundation tight against water, and only consider the question of the relative resistance of the earth strata and the rock-bed to vertical pressure, a cushion of sand extending over both for a short distance, of sufficient depth to distribute the pressure, and wide enough to minimize the unit strain on the soft material, is effectual. I have done that with several heavy structures, and have had no trouble whatever, any tendency to crack being distributed over such a length of wall that no harm results. I do not know whether the author of the paper resorted to that in this case or not; and I would like to ask his judgment concerning it, assuming that by benching into the natural formations, and sealing the sand cushion on the side with concrete, the question of percolation can be eliminated.

Charles Macdonald, M. Am. Soc. C. E.—When the author of the paper speaks of coarse sand as being the best, there may be room for a decided difference of opinion in view of the results obtained by what is known as the Danish process, in which sand and cement are first ground together, and then this sand-cement mixed with coarse sand. It has been stated by parties interested in the process that considerable economy in cement may be effected by this combination.

It would certainly seem reasonable to assume that the smaller the void spaces between the particles of sand, the less cement would be required.

R. W. Lesley, Assoc. Am. Soc. C. E.—If I am not mistaken it was at the time the author was constructing these dams that he made some comparative tests of sand. I thought it was a most ingenious thing to do. My recollection was that the contractors were getting sand from some distant point, and that they wanted to use some sand that was found near the work, and that he took standard sand and tested it with the brand of cement he was using, and then made other tests, with the same cement, of the other two sands referred to, and that as

a result of these experiments it was found that as compared with the standard sand, the sand found near the work was the best one for use. I have often spoken of this matter of testing sand, and I think the author was the first man that ever did it. I thought it was a very ingenious way of determining the question. We have made some experiments with sand and some cement that was sent us and got excellent results, but examining it in a commercial way, the conclusion was that the sand process used in Denmark, where they have no natural cements, and, I am told, very little lime, would be of much more value in that country than here. The admixtures in mortar gave results at 28 days very closely approximating in strength and in cost the results gotten from our natural cements with sand mixtures, and while the results in both cases were excellent, the net cost of a mortar composed of sand cement, the mortar being of a given strength, would not be any cheaper than a mortar with natural cements. The process has some very interesting features, but from the commercial side we could not see where the commercial advantage was in a country where we have such excellent natural cements as we have here. In Denmark, where the natural cements do not exist, it is of commercial value. In the United States, however, natural cements, which with 2 or 3 parts of sand, will be as strong as a commercial sand-cement in equal sand mixtures, can be made cheaper than the sand-cement which requires the washing and drying of the sand and the grinding of the same with Portland cement clinker to fit it for the market.

F. Collingwood, M. Am. Soc. C. E.—The question of pointing has been referred to in this discussion. There is one very important thing to be remembered in this connection, that it is not safe to do pointing after frosts begin in the fall. The experience on the East River Bridge was, that failure was quite sure to result if this were done. The joints should be absolutely free from dirt, sand, or fragments of mortar, and thoroughly wet before the pointing is inserted. In very high structures still another precaution must be taken. In such cases a sensible compression takes place in the joints, and if the arises be cut sharp, and the pointing done before the masonry above has obtained much height, the compression will surely cause spalling and disfigurement. This was the case on the lower portion of the Washington Monument. In the upper portion the rule was adopted of slightly beveling the horizontal joints for about 1 in. back from the face, and no pointing was done until at least 40 ft. of masonry was built above. On the part thus built no spalling has occurred.

In the Vyrnwy Dam, the pointing was from 3 to 6 ins. deep, and it was kept back ¼ to ¾ in. from the face.

Alexander Potter, Assoc. M. Am. Soc. C. E. (by letter).—There is one point on which the author did not touch in his paper, namely, the practicability of altering the location of the railroads on either side of

the reservoir instead of constructing expensive retaining walls to protect them.

From the rear of the train in passing the point in question there seems to be no unsurmountable engineering difficulty in the way, excepting probably that of grades. The author states, however, that at the dam the grade of the road is but 1 ft. per 100, which is much less than the average grade of the Delaware, Lackawanna and Western from Scranton to a point beyond the dam. The cost of these retaining walls would reconstruct many thousand feet of railroad, and at the same time would remove the danger which the author himself considers within the range of possibility. The writer has no doubt that the author had excellent reasons for not changing the roadbed of these railroads, but thinks that some mention should be made of why it was not done.

In regard to the crack in the wall along the Delaware, Lackawanna and Western tracks a somewhat similar crack occurred in the Beetaloo Dam, described in the *Minutes of Proceedings* Inst. C. E., Vol. CXIII. While stating that three different causes might have produced this defect in the dam, namely, settlement of foundation, contraction due to temperature and earthquake, the engineer in charge advanced the theory "that the shale bands which are wider at the higher levels of the western end of the dam (the cracked end) than at any other point became saturated with water, swelled and lifted the western end upwards and outwards."

The exact nature of the crack and the method of closing it is fully described in the paper referred to.

The author's suggestion that the raking out and pointing of masonry work be left until after the reservoir has been filled is an excellent one, as without doubt many reservoirs remain perfectly tight only as long as the plastering remains in the joints.

The only objection that could be raised is that with the larger reservoirs, when once filled, a strong feeling usually exists among the local people that it will be impossible to fill it again, and so the pointing goes by default.

E. Sherman Gould, M. Am. Soc. C. E.—Replying *seriatim* to those who have discussed my paper, I would say that the details furnished by Mr. Worthen of the construction of the Cohoes Dam are very interesting, and I am glad that some description of this important work has been called forth. The low facing wall of composite construction, shown in the figure as being placed against the old crib structure, differs widely in character, however, from the retaining wall built along the Delaware, Lackawanna and Western track in the Dunning's Dam. This latter wall stands, for a great part of its length, entirely exposed on its top and both sides to the changes of temperature, and is, moreover, lighter in section, so that it can be easily penetrated by heat and

cold. It is, besides, perfectly compact and homogeneous, the only exception to this statement being the fact that the coping is of larger stones than those in the wall immediately below it, and partakes, as coping necessarily must, somewhat of the nature of a superadded and independent piece of work. It may be readily imagined that a structure made up, as the Cohoes wall was, of three or four different classes of work, which it would be impossible to bond together as thoroughly as if composed throughout of only one class, should offer a certain amount of play within itself, and thus take up any expansion or contraction which might occur.

My thanks are due to Mr. W. R. Hutton for his clear appreciation of the peculiar difficulties with which the construction of the dam was surrounded, and of the means adopted to overcome them. The possible softening of the ground on which the long retaining wall stands, referred to by Mr. Hutton, was certainly the most serious cause for apprehension in regard to this feature of the work. The design upon which this wall was built has, however, proved itself to be entirely adequate. The precaution of a transverse joint at certain distances, adopted by the Dock Department of New York, was inadmissible in the present case, and the only thing to do was to found and build the wall as well as possible, and let it take its chances as to expansion and contraction. Perhaps introducing occasional short returns, or offsets, would be advantageous in such walls.

As regards the arrangement of gate-houses referred to by Mr. Hutton as having been adopted by French engineers and others, I am in hopes that a careful study of the plans accompanying my paper may convince others, as I was fully convinced myself, that the system therein shown is greatly superior to the one suggested. It will be seen by the plans and description that the "gate-house" referred to as being placed at the foot of the inner slope of the embankment has been advanced in the Dunning's Dam till it comes into actual contact with and forms part of the main dam itself. By this means access is obtained to the "tower" (as I have termed it) without the need of a bridge or a boat. Great strength is also secured, and the danger of injury or destruction to an isolated tower standing far out in the reservoir from ice and other causes wholly avoided. I called especial attention to this because it seemed to be worthy of careful consideration. It will be seen that the "more detailed regulation" was accomplished in the way referred to by Mr. Hutton. Only I had two sets of stop-cocks instead of one, and two vaults, or gate-houses, which were built separately and connected by a short gallery, which separation I now consider unnecessary, and in another case would certainly make a careful study for a plan uniting the two sets of gates in one gate-house, although such study might, after all, lead me back to my original design.

As Mr. James Owen instances, an impervious dam may be built of pure white sea sand, provided the escape of the sand can be prevented. It is in this way that the dams used for flowing the cranberry bogs in South Jersey are built. A trench is dug through the muck down to the underlying white sand, on each side of which a wall of sods or "floats" is placed, and the interval between these walls filled in with sand of the same character as the subsoil. The result is perfectly satisfactory.

The remarks and examples contributed by Mr. Kenneth Allen are interesting and valuable. I am inclined, on general principles, to prefer a stepped face for the overflow, wherever practicable, for the reasons stated in the paper. Each case, however, should be studied separately in view of the varying conditions. One fact, however, will always remain, and that is that there is safety in a wide and substantial apron extending well beyond the foot of the dam proper, unless it stands upon rock so solid as to render this precaution unnecessary.

As regards the question whether an earthen embankment relieves a wall of a portion of the water pressure, I think there can be no doubt that it does relieve it. The theory sometimes advanced, that the bank should be considered as saturated and semi-fluid, and therefore augmenting rather than diminishing the pressure upon the wall, is best opposed, I think, by the fact that many dams are built wholly of earth, and so far as I know they resist very well, when not overtopped by floods, or penetrated by water following the pipes or culverts running through them. I do not recollect hearing of one failing by slowly melting away from end to end, which would be the case if it become saturated and semi-fluid. I consider, therefore, that a good earthen backing is an element of safety to a masonry dam, although our calculations should never be run so fine as to include an allowance for diminished thrust against the wall, for the object of the bank is rather to prevent leakage, shock and variation of stress, than to lessen pressure.

I did not try the expedient suggested by Mr. Foster Crowell, of covering the junction of the rock and earth foundations with a cushion of sand, with the view of distributing the pressure more evenly. I think that, with proper precautions, a more even bearing might be thus obtained, but I should be very averse, after reaching rock, to cover it over again with a less solid material. I would take what rock I could get, and be thankful for it, and do the best I could with the earth, preferring to have a part better than the whole rather than reduce the whole to a uniform inferiority.

The remarks of Mr. Charles Macdonald apply to a subject brought out in the oral discussion, and not forming part of the paper. I believe that the better results usually obtained with coarse sand are due to the fact that a given volume of coarse sand contains more voids,

and, therefore, more cement than an equal volume of fine sand. If just enough cement were added to a certain volume of coarse sand to exactly fill the voids, to just saturate it, so to speak, it would be found that a smaller quantity of cement would suffice to saturate an equal volume of fine sand, because the volume of the voids would be smaller. A briquette made from the coarse mixture might, therefore, be reasonably expected to "pull" higher than the other, because it would contain more cement.

Mr. R. W. Lesley is correct in the matter of the sand test made to determine the relative value of two different kinds of sand. I doubt, however, if I can claim to be the first to use a testing machine for this purpose, because it seems a very natural thing to do when doubt exists as to the quality of the sand. In the present case, it somewhat oddly happened that the sand which, judged by its appearance, should have been inferior, proved to be superior to the other when actually tested.

There can be no doubt that Mr. Collingwood is perfectly correct in saying that pointing should not be done in freezing weather. It is a difficult job at best, and all conditions should be favorable when it is undertaken.

As Mr. Alexander Potter suggests, the necessity of a retaining wall would have been obviated by shifting the track of the railroad sufficiently up hill, and there would have been no engineering difficulty involved in doing so. Other reasons, however, in the present case, made this expedient appear impracticable, and although it was suggested to me at the time as a possible solution for the problem, the idea was not entertained.

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RAILROAD SIGNALING.—THE BLOCK SYSTEM.

By JOHN P. O'DONNELL, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1894.

WITH DISCUSSION.

It will be the endeavor of the author in the course of this paper to trace the various stages and developments which not only led to the ordinary block working on railways, as now generally in use, but also to the introduction of the interlocking system, which, in combination or union with the block system, seems likely to be the signaling of the future.

In viewing the past history of the block system, it appears strange to us to think that such strenuous opposition was offered to the introduction of even the earliest and most simple forms of block working. The author will endeavor to abridge the records as far as they are obtainable from papers and discussions laid before the various institutions, and from published pamphlets, and compare the general consensus of opinion at the various times and dates of these papers with the various systems in operation at the present date.

The opposition to the introduction of the block system seems parallel to the opposition offered to the earliest railways, and although the pioneers of railways had greater obstacles to overcome than those who have endeavored to persuade the railway companies for their own benefit to adopt the block system, yet improvements on the latter have not been, curiously enough, generally introduced until the stipulated number of years of the life of the various patents have elapsed.

Although this may appear a strange coincidence, yet it can be accounted for by the general hesitation of managers and other responsible officials to enter upon what appeared to them to be an experiment or new departure. The earliest record of the introduction of railways is probably that given in the life of Lord Keeper North, from which it appears tramways were first made use of about the year 1670, for transporting coal from the mines near Newcastle-on-Tyne to the place of shipment. These at first consisted of wooden rails or trams imbedded in the road, to which a second wooden rail was afterwards added, to facilitate repairs and renewals; and these wooden rails were later covered with malleable iron to reduce friction. This last advance was made about the year 1716.

In approximately another hundred years the locomotive steam engine was in use, and railways as now understood were inaugurated with the opening of the Stockton and Darlington Railway on the 27th of September, 1825. It will be observed that something like one hundred and fifty years were absorbed in obtaining the most out of the introduction of the tramway in 1670, and that improvements were slow to be adopted.

Since 1825, the locomotive and the track have remained substantially the same, and the author will endeavor to trace a parallel in the block working of railways, the several stages of improvements and the final result being a little more than an amplification of the devices and ideas laid down in the initial stages. The railroads in their infancy met with great opposition; survey parties went out armed, and often during the night, and Mr. Vignoles, the celebrated engineer, tells how he was arrested while making a moonlight survey and brought before a magistrate (Mr. Bradshaw) on a pretended charge of night poaching.

Mr. Vignoles, in his address to the Institution of Civil Engineers (England), in 1870, mentions this fact, and expresses his belief that

the acquaintance (and subsequently the assistance) of Mr. Bradshaw, brought about in the manner above cited, assisted largely in overcoming the opposition on the part of the Marquis of Stafford and his family to the Liverpool and Manchester Railway.

As the number of trains on railways became larger, it was recognized that it was necessary to establish some kind of system to minimize the risk of collisions from their regular working of trains. The first idea suggested was to allow an interval of time to elapse between the passing of trains at given points, generally, for the sake of convenience, the stations; and, singularly enough, most American lines have not advanced beyond this.

It might here be pertinent to ask the following questions:

What is the Block System?

What is the Interlocking System?

What is the Union of the Lock and Block Systems?

What is an Automatic Block System?

Taking these questions in their order, the block system, as we understand the words, means maintaining a space interval between trains on the same pair of rails. For space intervals substitute "block" or "section," and we have it that a clear block or section, or, as the American Railroad Association puts it, "a length of track of defined limits," is maintained between trains. The American Railroad Association in its rules has not defined "the defined limit," and as this appears an important question, and one that has led to some discussion, perhaps the author may be excused in stating what appears to him to be the true definition of a block section. A block section is the whole of the track from the most advanced signal in a section to the most advanced signal in the section ahead. Briefly, it is the whole of that part of the railroad on which visual signals will, if obeyed, prevent the entrance of a train into the section ahead.

The object of the block system in maintaining an interval of space between trains is to prevent collisions, and Dr. Johnson defines the word collision as an act of "striking together"; the word together sums up the situation, for in order to effect a collision two bodies (frequently moving at high velocities) must be brought into contact with each other. It clearly requires little reasoning that a collision cannot occur with one train only (such train to be provided with automatic brakes, and assuming their working is correct); and it

further follows, by a parity of reasoning, that if the next following train on the same rails is always kept a length of track of "defined limits" apart from the preceding train, the act of striking together (as Dr. Johnson puts it), or collision, of the two trains, cannot under any circumstances occur.

Next, what is an interlocking system? An interlocking system is intended to prevent conflicting switches from being opened at the same time, conflicting signals from being at "safety" at the same time, and conflicting signals and switches from being operated at the same time. The interlocking system is distinguished from the block system in so far that it is intended to provide safety only in the section in which it is applied. A block system by itself is of considerable value where no switches are connected with the passenger roads. Again, an interlocking system, as previously stated, affords safety in its own section. Neither one is complete without the other, even where the two are separately installed. The legitimate amount of safety which the public has a right to expect is not afforded.

This leads us to the third question, what is meant by the union of the lock and block systems? The union of the lock and block systems is the interlocking, or interdependence or amalgamation, of the block system as a whole and the interlocking system as a whole. Here it might be well to ask, what result does the present so-called lock and block system give us? For a block system, pure and simple, a home signal and a distance signal must be provided; but, for the purpose of this third question, let us suppose a starting signal is added. This, or its operating lever, is electrically controlled by the section in advance in any of the known lock and block systems. We, therefore, do not derive any substantial benefit from the interlocking system, for there is practically no interlocking in the ordinary sense of the word included in this combination. There is electrical control, certainly, but the advantages of the mechanical interlocking of switch and signal levers is not attained.

What is an automatic block system? The American Railroad Association defines it as a system which is self-operative, whether by mechanical, electrical, pneumatic, or other device. The meaning is clear, but it may be asked, is it self-operative? Does not the train command the section, and itself actuate all the signals? It would appear that strictly speaking, the word "automatic" in this application is a

misnomer. Would it not be better to call it "non-manual" or "train-operating block system"? Any power system, whether mechanical, electrical, pneumatic or hydraulic, may be classed as "manual." The difference is between those that depend upon human agency for the initial operation, and those that do not. The author begs leave to dissent from the American Railroad Association's description of a "home block signal." The author, having raised ample matter for discussion, will now give a retrospective sketch of block working.

In December, 1839, Messrs. Cooke & Wheatstone induced the Great Western Railway to telegraph the arrival and departure of their trains from station to station between Paddington, West Drayton and Hanwell. In 1841 the same gentlemen introduced separate instruments for signaling the trains each way, these instruments showing at a glance whether the line was "clear" or "blocked." These instruments were provided with pins to hold the needles over to either side so that the needle would show "line clear" or "line blocked," as desired; practically, so far as the result aimed at is concerned, this remains the accepted system of to-day in Great Britain. Bells were also added, and as early as 1841 the principle of the block system of the present day was established.

The great credit of introducing the block system, as it is now understood and worked, is due to Sir William Fothergill Cooke, who, as Mr. Cooke in 1842, published his pamphlet entitled "Telegraphic Railways," in which, specifically, the leading principles of the block system were explained.

It is curious in following the opening of this pamphlet to read that Sir William Cooke had two objects in publishing it. The first was—

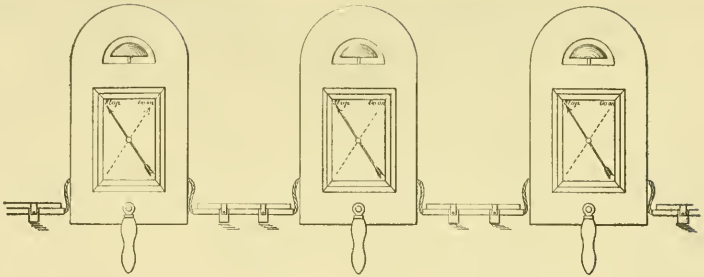
"To add to the safety and efficiency of railway communication, by means not more but less expensive than those now adopted" (1842). The second was "to overcome some objections to the formation of auxiliary single lines, by suggestions calculated to give them the safety and efficiency supposed to be exclusively within the reach of double lines." Sir William Cooke states that: "It is proposed to accomplish these objects by the electric telegraph, the application of which is, it is hoped, clearly explained in the subjoined statement." Further he says that: "It may be considered that the maximum degree of safety and efficiency attainable by subsidiary regulation is already secured on the great double lines of railway," and that "to the comparatively high degree of safety now obtained in railway traveling (1842) depending then, as I have said, upon the vigilance and punctuality in the conduct

of the trains, it is proposed to superadd a physical certainty of their relative places on the line at any moment."

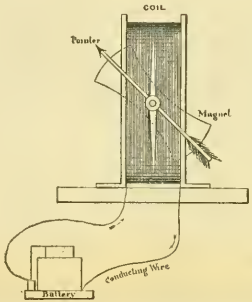
Sir William Cooke, in the course of his paper, described the principles and action of the instruments on the Blackwall Railway, as follows :

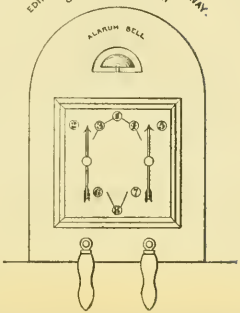
"The principles on which the electric telegraph is constructed are founded on Oersted's celebrated discovery that a magnetic or compass needle may, through the agency of a voltaic current, be invested with an artificial polarity. Thus, as a natural stream of electricity, passing round the circumference of the earth, causes magnetic needles in general to be deflected at right angles to its course, or towards the north and south poles, so an artificial stream of electricity, of adequate strength, will cause magnetic needles, placed within its influence, to be similarly deflected at right angles to its course, whatever that may be. If, then, a magnetic needle were placed parallel and near to any part of a conducting wire, which we will suppose to be laid down between London and Blackwall, the transmission of an electric current from a voltaic battery will cause the needle to change its position so as to stand during the continuance of the current at right angles to the wire, being turned in one direction or the other, according to the course of the current. If this deflection of the needle were limited by two fixed stops placed respectively at the two sides of one of its poles the motion of that pole to one stop might evidently constitute one signal and its motions to the other stop, another signal."

"The annexed engraving (Plate LX) represents some of the Blackwell Railway instruments, constructed upon the principles above explained. The signals are given by pointers, each suspended vertically on an axis, moving freely through the face of a dial. Behind the dial a magnet is fixed on the same axis as the pointer, so that both move together. A portion of the conducting wire is coiled many times longitudinally round a frame, in which the magnet moves, so as to subject the magnet to the multiplied deflecting force of the voltaic current. The motion of the magnet is limited at both sides by fixed stops. Now, suppose three of these very simple instruments, included in the same conducting wire, to be placed one at the Minories, a second at Blackwall, and the other at some third point. The general effect of this arrangement would be that the transmission of electricity along the conducting wire, and therefore through the convolutions of wire surrounding the respective magnets, would deflect those magnets with a sudden and decided motion to one of the stops, and cause the exterior pointers to indicate corresponding and simultaneous signals upon the dials of the three instruments. Each instrument is provided with a battery, and a handle, by which a porter or policeman is enabled at pleasure to connect the conducting wire with his battery. By

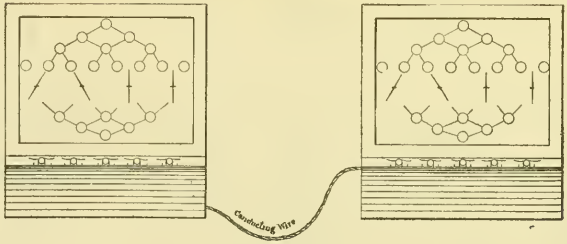


EDINBURGH AND GLASGOW RAILWAY.
8 SIGNAL TELEGRAPH





TELEGRAPH ON THE GREAT WESTERN RAILWAY.



moving the handle to the right or left, either of the signals can be instantaneously transmitted from any one of the instruments to all the others, which, by means of their own handles, have the power of sending back signals in reply, correctness being ensured by the simultaneous appearance of the signal in the instrument of the operator and that of the recipient. The transmission of intelligence is prefaced by sounding a bell by which attention is obtained, an operation effected through the agency of the voltaic current."

The engraving also represents one of the instruments upon the Edinburgh and Glasgow Railway, being a combination of two of the above elementary telegraphs. Each needle is here worked by its distinct handle. By the single movements of the pointers, the figures 2, 3, 4 and 5 may be given. If the two pointers are made to converge upwards at the same time, their combined indication will be the figure 1; or if they converge downwards, 8. If the pointers are made to rest diagonally, parallel to each other in one direction, 6; in the other, 7 is indicated. Eight distinct signals are thus obtained, which, in connection with a code, are sufficient for all ordinary purposes. By combining several elementary telegraphs, any number of signals may be obtained. A drawing of the telegraph employed on the Great Western Railway, worked by keys, and having a peculiar arrangement of the conducting wires, not necessary to be explained, is subjoined to illustrate this point.

Plate LXI illustrates the modern single needle instrument used for block working, and as generally in use in England. Fig. 1 is a front view, showing the outside appearance of the instrument. Fig. 2, a front view, with the cover and that part of the case carrying the operating handle removed ; and Fig. 3, a side view.

The material difference in principle in this instrument to that introduced by Messrs. Cooke & Wheatstone is in the substitution of a soft iron armature inside the coils in place of a permanent magnet, and the addition of a comparatively large permanent magnet outside the coils to control the position of the armature when no current is passing through the coils. Beyond this, the improvement consists in the better form and construction of the instrument in its various details.

The instrument in its present form is much less liable to be affected by lightning or earth currents, and, if affected, will only be momentarily so. Should the polarity of the permanent magnet be reversed, it would not affect the working of the instrument.

Cooke & Wheatstone's block system was put into operation on the Norwich and Yarmouth Railway in 1844. It is curious that in this instrument the exact words which are now most generally adopted in England, viz., "line clear" and "line blocked," were actually employed.

Notwithstanding the efforts made, both before and after the year 1844, it is curious to note the various changes which took place in block working on railways before the present system was adopted, which is practically the same as the early forms described by Cooke & Wheatstone.

In the winter of 1843–44 an accident occurred on the Lickey incline of the Birmingham and Gloucester Railway; and as a consequence, block working was introduced and carried out by complete telegraphic messages in place of arbitrary signs, "line clear" and "line blocked."

In 1851, Mr. C. V. Walker, the telegraphic engineer of the Southeastern Railway, suggested the carrying out of block working by a code of rings on bells, and for upwards of 12 years the trains of the Southeastern Company were worked by audible electric signals. Throughout these 12 years no single needle instrument or its equivalent was used, the whole of the telegraphic signaling of the trains being carried on exclusively by sound. In 1855 the same company made a trial at Tunbridge of a form of block instrument having two miniature semaphore arms in place of the needles. This, the author believes to have been the first instance where an attempt was made to assimilate the block instrument with the outside visual signal.

From this time onward the block systems adopted on the various railways could be classed in two divisions, the great majority using the needle instrument as described by Cooke, the remainder employing the semaphore instrument as introduced by Mr. Walker.

In the comparatively early days of signaling there were three papers read before the Institution of Civil Engineers (England) on "Railway Accidents." The first by Capt. Huish, in 1852; the next by Sir James Brunlees, and the last by Sir Douglas Galton, R. E., F. R. S., the last two papers in 1861. As bearing on the time interval of block working, Sir James mentions the Welwyn accident on the Great Northern Railway. He says:

"On the Great Northern Railway in the Welwyn accident, only one train out of four which were concerned kept its time, and this one ran

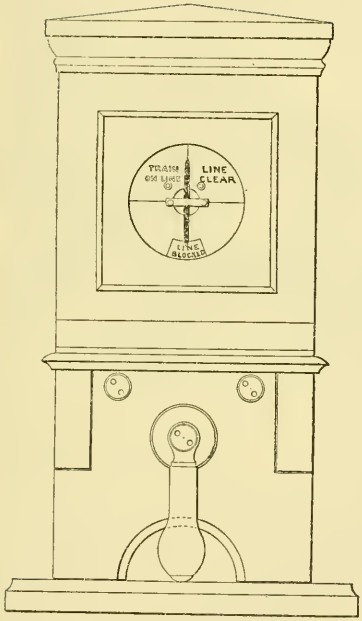


Fig. 1

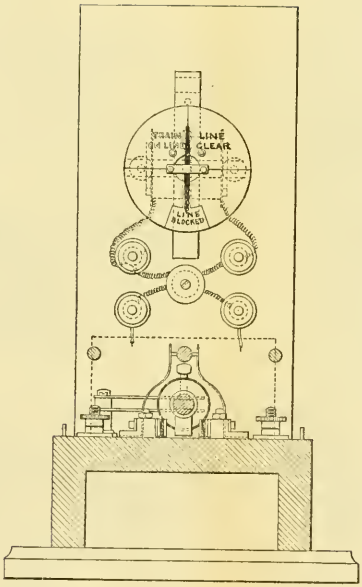


Fig. 2

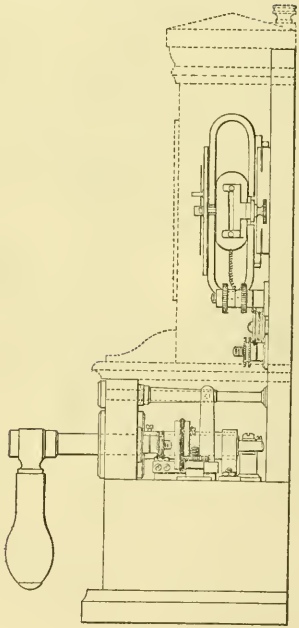


Fig. 3

into another which was an hour too late. On the same line in a collision at Hatfield, the three trains concerned were, respectively, 3 hours 10 minutes, 2 hours 47 minutes, and 1 hour 40 minutes late. In an accident on the London and Southwestern Railway, a passenger train timed to run 26 miles per hour was started two minutes after a goods train timed to run at 16 miles per hour, and, as a consequence, the passenger train ran into the goods train before it had gone 4 miles from the starting point. The number of instances in which unpunctuality and the starting of one train too soon after another have been the cause of accidents are far too many to be referred to separately. The author need, however, only allude to the Clayton tunnel accident to illustrate his remarks on this head.

"A general rule has been laid down that five minutes ought to elapse from the starting of trains from each station, but this cannot be made generally applicable, as so much depends on the class of trains succeeding each other, such as their rates of speed, or there being stopping trains or otherwise. In many instances an interval of five minutes may be enough, but in others it is manifestly insufficient, for, though trains may be started from a station at the stated intervals, they will, from various causes, be unable to preserve the same distance from each other. More attention is required to this point than to that of their starting. The system of working the traffic of a railway by allowing an interval of time between the trains is unsatisfactory and dangerous, and far inferior to that of allowing an interval of space."

An amusing incident bearing on time interval, showing how even allowing an enormous latitude is not sufficient, came under the author's notice. A train started from a terminus on Monday, and another on the following Wednesday (the exact hour is a mere detail), and Wednesday's train collided with Monday's. Sir Douglas Galton, R. E., F. R. S., in his paper, says that about that time (1862) between £100 000 and £120 000 was annually paid as compensation for railway accidents.

From the published returns for the year 1854 upon accidents in Great Britain, it appears there were 85 accidents specially reported upon, resulting in the following, viz.:

Killed	233
Injured	453

of which numbers 283 suffered in collisions between trains. Of these 85 accidents there were no less than 52 which arose from collisions, or nearly 61.18% of the accidents from all causes.

Compare this with the Board of Trade returns for 1893.

SUMMARY OF ACCIDENTS AND CASUALTIES WHICH HAVE BEEN REPORTED TO THE BOARD OF TRADE AS HAVING OCCURRED UPON THE RAILWAYS IN THE UNITED KINGDOM DURING THE YEAR ENDING DECEMBER 31ST, 1893.

1. *Accidents to Trains, Rolling Stock, Permanent Way, etc.*—Accidents to trains, rolling stock, permanent way, etc., caused the death of 27 persons and injury to 557 persons, viz.:

	Killed.	Injured.	Total for the Year 1892.	
			Killed.	Injured.
Passengers	17	484	21	601
Servants of companies	10	73	9	92
Total	27	557	30	693

During the year there were reported 27 collisions between passenger trains or parts of passenger trains, by which 86 passengers and five servants were injured. Forty-five collisions between passenger trains and goods or mineral trains, etc., by which 157 passengers and 11 servants were injured. Twenty collisions between goods trains or parts of goods trains, by which one servant was killed and 17 were injured; two cases of trains coming in contact with projections from other trains traveling on parallel lines, by which one servant was killed and three passengers were injured; 54 cases of passenger trains or parts of passenger trains leaving the rails, by which 15 passengers and five servants were killed, and 82 passengers and 11 servants were injured. Eleven cases of goods trains or parts of goods trains leaving the rails, by which one servant was killed and two were injured; seven cases of trains or engines traveling in the wrong direction through points, by which one servant was killed and five passengers and one servant were injured; 23 cases of trains running into stations at too high a speed, by which 121 passengers and five servants were injured; 162 cases of trains running over cattle, or other obstructions on the line, by which one person was killed and 16 passengers and other persons were injured; 40 cases of trains running through gates, at level crossings, by which one passenger was killed and one servant and two other persons were injured; four cases of the bursting of tubes of engines, by which one servant was injured; 10 cases of the failure of machinery, springs,

etc., of engines, by which four servants were injured; 468 cases of failures of tires, by which one servant was injured; 18 failures of couplings, by which one passenger and seven servants were injured; one case of the failure of ropes used in working inclines, by which one servant was injured; four cases of slips in cuttings or embankments, by which one servant was killed and five passengers were injured; and four other accidents by which four passengers and five servants were injured.

Taking the enormous increase of traffic of to-day, as against the year 1854, and the correspondingly large decrease of accidents, is it not fair to place a great deal of the credit of this most satisfactory result to the employment of reliable signaling? Some railway managers think that the latest developments of signaling tend to hamper their traffic, while others, that the cost is so great they cannot afford it; but let them take their annual accident bill and capitalize it and see how large an amount of signaling they can obtain for it in these days of keen competition; to say nothing of avoiding the discredit of accidents, while being, as they undoubted would be, pioneers in safe railway traveling, and if they are philanthropic, why they are public benefactors (not to the contractors, but to the traveling public).

The author gladly avails himself of this opportunity to pay his tribute of respect to the forethought and impartial conduct of the inspecting officers of the British Board of Trade. To that department the British public owes the immunity from accidents which has characterized the management of British railways during many years passed. The first rules issued by the department, so far as the author is aware, were issued by the Lords of the Committee of the Privy Council on April 29th, 1858. The much-discussed question of interlocking and the supposed credit due to its inventor is somewhat discounted by these rules. Even safety switches were enforced. Year by year additions have been made, culminating in the Regulation of Railways Act, passed by both houses of the British Parliament in 1889.

It might interest this Society to give the leading features in regard to signaling in the latest rules issued, August, 1892, by the British Board of Trade. They are as follows:

B.—Requirements.

First.—The requisite apparatus for providing by means of the block telegraph system an adequate interval of space between following

trains, and, in the case of junctions, between converging or crossing trains. In the case of single lines worked by one engine under steam (or two or more coupled together) carrying a staff, no such apparatus will be required.

Second.—Home signals and distance signals for each direction to be fixed at stations and junctions, with extra signals for such dock or bay lines as are used either for the arrival or departure of trains, and starting signals for each direction at all passenger stations which are also block posts. On passenger lines all cross-over roads and all connections for goods, mineral lines and sidings to be protected by home and distance signals, and, as a rule, at all important running junctions a separate distance signal to be provided in connection with each home signal.

Signals may be dispensed with on single lines under the following conditions:

(*a*) At all stations and siding connections upon a line worked by one engine only (or two engines coupled together), carrying a staff, and when all points are locked by such staff.

(*b*) At any intermediate siding connection upon a line worked under the train staff or ticket system, or under the electric staff or tablet system, where the points are locked by the staff or tablet.

(*c*) At intermediate stations which are not staff or tablet stations upon a line worked under the electric staff or tablet system, sidings, if any, being locked as in *b*.

Third.—The signals at junctions to be on separate posts or on brackets ; and the signals at stations, where there is more than one arm on one side of a post, to be made to apply—the first or upper arm to the line on the left, the second arm to the line next in order to the left, and so on; but in cases where the main or more important line is not the one on the left, separate signal posts to be provided, or the arms to be on brackets. Distance signals to be distinguished by notches cut out of the ends of the arms, and to be controlled by home or starting signals for the same direction, when on the same post. A distance signal arm must not be placed above a home or starting signal arm on the same post for trains going in the same direction.

In the case of sidings, a low short arm and a small signal light, distinguishable from the arms or lights for the passenger lines may be employed, but in such cases disk signals are, as a rule, preferable.

Every signal arm to be so weighted as to fly to and remain at danger on the breaking at any point of the connection between the arms and the lever working it.

Fourth.—On new lines worked independently, the front signal lights to be green for "all right," and red for "danger"; the back lights

(visible only when the signals are at danger) to be white. This requirement not to be obligatory in the case of new lines run over by trains of other companies using a different system of lights.

Fifth.—Facing points to be avoided as far as possible, but when they cannot be dispensed with, they must be placed as near as practicable to the levers by which they are worked or bolted. The limit of distance from levers working points to be 180 yds. in the case of facing points, and 300 yds. in the case of trailing points on the main line, or safety points at sidings.

In order to insure that the points are in their proper position before the signals are lowered, and to prevent the signalman from shifting them while a train is passing over them, all facing points must be fitted with facing point locks and locking bars, and with means for detecting any failure in the connections between the signal cabin and points. Length of the locking bars to exceed the greatest wheel base between any two pairs of wheels of the vehicles in use on the line, and the stock rails to be tied to gauge with iron or steel ties. All points, whether facing or trailing, to be worked or bolted by rods and not by wires, and to be fitted with double connecting rods.

Sixth.—The levers by which points and signals are worked to be interlocked, and, as a rule, brought close together, into the position most convenient for the person working them, in a signal cabin, or on a properly constructed stage. The signal cabin to be commodious and to be supplied with a clock and with a separate block instrument for signaling trains on each line of rails. The point levers and signal levers to be so placed in the cabin that the signalman when working them shall have the best possible view of the railway, and the cabin itself to be so situated as to enable the signalman to see the arms and the lights of the signals, and the working of the points. The back lights of the signal lamps to be made as small as possible, having regard to efficiency, and when the front lights are visible to the signalman in his cabin, no back lights to be provided. The fixed lights in the signal cabin to be screened off, so as not to be mistakable for the signals exhibited to control the running of trains. If, from any unavoidable cause, the arm and light of any signal cannot be seen by the signalman, they must, as a rule, be repeated in the cabin.

Seventh.—The interlocking to be so arranged that the signalman shall be unable to lower a signal for the approach of a train until after he has set the points in the proper position for it to pass; that it shall not be possible for him to exhibit at the same moment any two signals that can lead to a collision between two trains; and that, after having lowered the signals to allow a train to pass, he shall not be able to move any points connected with, or leading to, the line on which the train is moving. Points, also, if possible, to be so interlocked as to avoid the risk of a collision.

Home or starting signals, next in advance of trailing points, when lowered, to lock such points in either position, unless such locking will unduly interfere with the traffic.

A distant signal must not be capable of being lowered unless the home starting signals in advance of it have been lowered.

Eighth.—Sidings to be so arranged that shunting operations upon them shall cause the least possible obstruction to the passenger lines. Safety points to be provided upon goods and mineral lines and sidings at their junctions with passenger lines, with the points closed against the passenger lines and interlocked with the signals.

Ninth.—When a junction is situated near to a passenger station, the platforms to be so arranged as to prevent, as far as possible, any necessity for standing trains on the junction.

Tenth.—The junctions of all single lines to be as a rule formed as double-line junctions.

For interesting information regarding the early forms, uses and experiments relating to block working on railways, the author has availed himself of the paper read by Mr. W. H. Preece, C. E., before the Institution of Civil Engineers, on June 13th, 1863. A perusal of both the papers and the discussion, and many of the decided opinions expressed therein, would startle some of the railroad men of the present day.

In the early stages one instrument was used for both up and down lines, and it was not to be wondered at that this system was the cause of accidents, notably the Clay Tunnel accident, when the telegraph, after working there satisfactorily for 10 years, failed at last.

To the London and Northwestern Railway is due the credit of two important advances in block working. Mr. Edwin Clarke, M. I. C. E., of that railway, was the first to introduce separate instruments for each set of rails, and, about the year 1853, a third position was added to the block instruments, which third position consisted of the needle being in the central (vertical) position intimating "line blocked." Constant currents were maintained on the wires of these instruments by pegging the needles over, as they do now, to one side or the other, and the wires were brought down to within reach at every alternate post, giving guards and other persons a means of communicating the occurrence of an accident by severing the wires which caused the needle to assume the vertical position. Bells on independent wires were used with this system of Mr. Edwin Clarke.

It is worthy of notice that the London and North Western Company only applied this system for permissive block working.

Mr. Preece truly says, that "this adulterated form of the block system is not sufficient under all circumstances to prevent collisions," and he instances the case which occurred near Wolverton on the 22d of February, 1862. Further he says:

"There are evidently great and serious objections to the working of railways upon the space or block system in preference to the time system," and states that "the London and North Western, the Great Northern and other railway companies have been compelled to abandon it. The telegraph becomes simply the medium of warning or caution, excepting in the case of long tunnels and steep inclines; it enables all slow trains or trains behind their time to hasten on because they are made acquainted of clear lengths before them; while all fast trains or trains before their time are informed that there is a train in front of them and are delayed without being actually stopped."

The London and North Western Company thought that the line could not be worked if a distance of 2 miles on an average was maintained between the trains, and it was of course obvious, as Mr. Preece remarked, that if 2 miles was a serious objection and an impossibility, why not shorten the distance?

In the light of later experience, railway managers had to, and did admit, that they could not work the heavy traffic passing over railways without the assistance and certainty afforded by the block system. This is specially so where trains follow each other at such short intervals as sometimes one, two, or three minutes.

It is believed to be a fact that even in the early days the Great Northern Railway of England, which is certainly a pioneer line and one that has all the latest improvements, used the two-needle instruments, and the needles were promiscuously used for the up or the down line as the occasion offered. The left-hand needle was used for passenger trains, and the right-hand one for engines, goods, cattle and ballast trains, and the signalman had to hold the handles to retain the needles in position.

Mr. Preece puts in instruments on his system (which was substituting the semaphore arm for the needle in the block instrument and thereby loosing the third position of the needle instrument) between Queen Street and St. David's Stations, Exeter, in March, 1862.

Briefly, Mr. Preece sums up the advantages of the application of

the telegraph to the working of single lines by stating "when the telegraph is used, safety is assured, regularity obtained, and single lines become as secure and rapid as double lines."

The author wishes it to be understood that in the retrospective part of this paper, in relation to the early defects of block working and the views expressed in the various papers, he is not offering any remarks of his own. The various documents containing these opinions are at the convenience of the public, and any historical retrospect of block working would be incomplete if the various changes of opinion in relation to the various systems were not incorporated.

The one remarkable feature is that the very first attempts at block working struck the right line, and, so far as the block working in England is concerned, substantially, it is the block working of to-day.

It was even stated in the discussion at the Institution of Civil Engineers in 1863, that one wire was an element of safety as well as economy, and further, with three wires, if a fracture of one of them took place, the fractured wire might foul one or both of the remaining wires, and that with a persistent current flowing, falsified signals might be sent. In the present system of working such an accident could not happen.

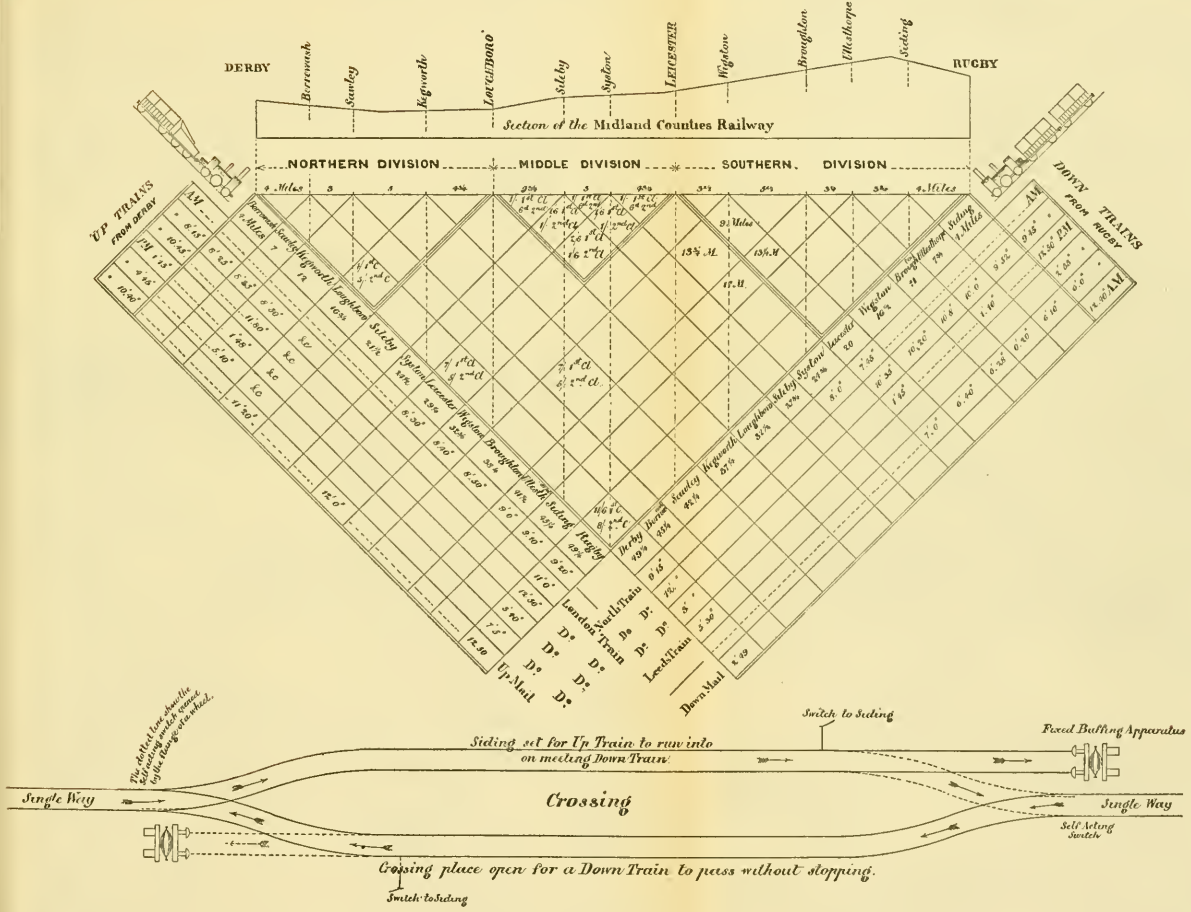
To Mr. C. V. Walker is due the credit of introducing the system that every signal made by one man should be correctly repeated by the man that received it as an intimation of the understanding of the signal.

Mr. Walker was also the first to use balanced currents for the working of bells. This knowledge was communicated to the Royal Society in 1857. It is a curious instance to find that a patent had been obtained for this purpose by another Mr. Walker, of Glasgow, anticipating in principle the invention of Mr. C. V. Walker, of the Southeastern Railway.

As early as 1856, Mr. Walker forwarded a paper on train signaling to the Institution of Civil Engineers, but, the subject not being then found attractive, it was not read.

In view of the fact that a large proportion of the automatic signaling which has been installed in this country has for its normal position the line at "safety," or the semaphore arm in the "safety" attitude, it may be mentioned that in the early days of railways, the line itself was considered as clear, but when sanction was given to the rear, that sanction intimated that the line was blocked. This, no doubt,

TIME, FARE AND DISTANCE TABLE



arose from the fact that there were only two positions to the instruments then in vogue, viz., "line clear" and "line blocked."

Sir William Cooke mentions this in his pamphlet previously referred to (1842). He says:

"I think it, however, highly desirable that the ordinary or quiescent condition of the station signal should be a state of danger, not a state of safety, so that a train should never run into a station without special guarantee that it was prepared to receive it. With such an arrangement no bad consequence could arise from want of presence of mind on the part of the signalman, at a moment of sudden danger."

There may be some members of this Society who will recall the fact that Mr. Ashbel Welch many years ago laid down the fundamental rule that the normal position for the outside arm should be danger.

It is a curious coincidence that in so many cases invention repeats itself, and that the old saying "there is nothing new under the sun" is very frequently verified. Rumors have reached us in Great Britain that certain claims have been put forward by parties in the United States for the monopoly on a patent for an alleged invention of safety switches, the object and use of which is perfectly understood. It may not be considered as exactly related to "lock and block" working, but as the writer has referred to the pamphlet of Sir William Cooke frequently in this paper, he may mention that in that pamphlet there is an interesting diagram of a time, fare and distance table (Plate LXII), the lower portion of which clearly indicates the use of safety switches for preventing accidents by trains overshooting the fouling point. It might, possibly, be better to quote his exact words with reference to this matter, and it should be borne in mind that this pamphlet itself was issued in the year 1842. He says:

"The arrangement of the rails and switches at a crossing is a matter of engineering detail. I have given a sketch which will sufficiently explain to the general reader the principle on which two trains might cross without the possibility of a collision, the self-acting switches infallibly directing them to the proper side. In case of a train accidentally proceeding further than necessary, its momentum would be checked by a fixed buffer apparatus, or a steep incline in the usual way."

The author would also point out that in the diagram referred to above the lines in question are passenger roads; therefore it is practically a derail on the passenger road.

The London and North Western Railway was the first, as previously mentioned, to introduce the third position in the needle instrument, and has to the present day maintained it, and, through its example, has influenced the large majority of railways in England to adopt the needle instrument with three positions. With this system when the needle is in the vertical position, the line is considered, according to the regulation words, as "not clear," and it is understood that, previous to sending a train, sanction must be obtained on the block instrument from the cabin in advance, the signal being repeated in acknowledgment to further ensure the understanding of the message, and the needle pegged over. When the third position was introduced, the great advantage which was no doubt desired previously, but which was difficult to obtain, was seen, and the normal position of the line as "not clear" or line "blocked" was hereafter established in all systems.

Even with the "lock and block" system the author believes that, notwithstanding the strong opposition to the normal "danger" position in automatic systems of signaling, as used in the United States at the present time, the contracting companies are making a specialty of offering such systems of automatic signaling that have a normal "danger" position for the semaphore arm. This is really following out the practice generally adopted 40 years ago in England.

In automatic signaling systems it should be borne in mind that while outside visual signals are the main feature, yet incidentally it becomes an actual block system in substitution of the block instrument in the cabin where the manual system is in operation; therefore, it should incorporate the advantages and result obtained from the manual and block instruments.

It is a curious fact that the objections which the author raises today against what is known as the "Sykes'" system of "lock and block," were substantially raised against the system of Preece, which had the miniature semaphore, in 1856, and the contradictory nature of the signals was plainly set forth then. In Mr. Walker's paper of 1856, four telegrams were enumerated which illustrated the method of question and answer which Mr. Walker then considered necessary; the first was: from A to B, "May I send a train?" given by A striking one blow to B; B's answer, "Yes, you may," one blow struck back by B. A then sends on the train, and, on its arrival, B sends to

A the message: "The train you sent is in safe," by striking three blows to A, intimating this, and A replies, "All right; I understand train is in," by striking three blows to B. These blows are struck on bells.

In 1863, Mr. Walker's chief reason in objecting to miniature semaphores in the block instruments was "because the second of the above-named four signals was always contradictory, and did not mean what was intended to be conveyed." The first question, "May I send a train," was answered with the words on the bell and index, "Yes, you may not"; that was, while the bell replied "Yes," the semaphore went up or the index went over, which meant "No." It was true that "No" was understood to refer to any train that might follow the one in question, although it did not say so; but some day the index might say "No" and mean "No."

This is curiously enough the case with certain lock and block systems of to-day, and the author will refer to them later in comparing the various lock and block systems.

In 1863 it was practically agreed, in the discussion at the Institution of Civil Engineers, that a block system should be made legally obligatory on railway companies, but, as an illustration of the slow march of governments, it was not until the Regulations of Railways Act, 1889, that it was made so. The author might even remark that he believes that it is not obligatory in the United States. One gentleman remarked in 1863 in the discussion at the Institution of Civil Engineers, that

"No doubt the block system for crowded traffic might answer very well, but so long as the traffic could be carried on without the necessity for its aid, there was, in his opinion, a positive advantage in ignoring it and depending on the ordinary mode of signaling."

Having briefly traced the early stages and development of block working, the author will now trace the introduction of fixed signals and development of interlocking between levers operating points and signals.

Fixed signals, without which, of course, no system of block working can exist, were first brought into general use with the opening of the Grand Junction Railway in 1838, and at about the same time on the Liverpool and Manchester Railway. The signals were in the form of a semi-circular or D-shaped board, elevated on a pole and revolving

through an arc of 90°. The disk towards the driver indicated "danger," and the edge "clear." A light for a night signal was used in connection with these disks. Several forms of signals have been suggested and tried since the above were brought into use, but at the present time the recognized forms of signals are the semaphore, for running lines (introduced by Mr., now Sir, Charles Hutton Gregory, K. C. M. G., Past President Institution Civil Engineers, on the Croydon Railway in the early part of the year 1842), and low-revolving disk signals for crossing, sidings, etc. The semaphore signal was an adaptation of the old form of semaphore used for telegraphing to short distances, and has proved to be, perhaps, the most important step in the development of railway signals.

With the adoption of fixed signals it soon became evident that, to avoid the giving of a signal contrary to the position of the switches of the main and siding crossings, some form of interlocking between the two must be devised.

We read of Mr. Atkinson, at East Retford, in 1852, providing a lock between a signal and a pair of switches, and in the following year Mr. Whitworth proposed a notched bar connected to the signal wire and crossing at right angles another notched bar working in connection with the switches.

As the number of switches and signals to be worked increased, it became advisable and necessary to concentrate the levers working the same together in one place, and the principle of interlocking a signal and a pair of switches being known, it would appear simple to interlock the levers concentrated together; but it was not until 1859 that complete lever-locking apparatuses were applied by Mr. Austin Chambers for Kentish Town and Willesden Junction. Mr. Farmer, however, claims that Mr. Saxby, in 1856, fixed at the Bricklayers' Arms Junction of the Brighton Railway a lever frame of 14 levers properly interlocked so that no signal could be given inconsistent with the position of the points, and that the arrangement was patented in that year (1856). No patent was taken out by Mr. Austin Chambers until 1860, and probably Saxby's patent of 1860, after Mr. Chambers', is the first of Saxby's which can be said to cover a complete interlocking lever frame. In 1867 the concentration of point and signal levers and the proper interlocking of the same really began with the introduction of Saxby and Farmer's spindle locking, Messrs. Stevens & Sons' tappet locking, and

Messrs. McKenzie, Clunes & Holland's system of interlocking. The next step was the catch actuating of the interlocking, designed by Messrs. Easterbrook and Saxby in the same year (1867).

From this time various forms of interlocking, both catch actuated and worked direct from the lever, and adaptations of interlocking for special purposes, have been devised, but the principle remains the same.

For some time the arrangement of fixed signals, with levers to work them, and the switches concentrated and interlocked and block telegraph working independent of each other, was thought to be quite safe and sufficient, but accidents have occurred which show that, owing to the forgetfulness of the signalmen, something more is desirable, *i. e.*, a combination of "lock and block," in such a manner that it is impossible for the outside signals to be lowered, excepting when the line is "clear" and the proper telegraphic signals have been given and accepted.

Automatic signaling is an attempt to obtain "lock and block," or "trains commanding the section," and eliminating human agency. It may be argued that all forms of automatic signaling meet the objections against fixed signals and block telegraph worked independently. With regard to purely mechanical automatic signaling, it is limited by distance, and may, for this reason alone, be dismissed as unsuitable.

Several systems of automatic signaling, operated mechanically, have, however, been tried.

In the year 1858 the North London Railway Company tried between Hackney and Kingsland Baronowski's self-acting block system. In this system when a train passed over a lever arrangement the signal was put to "danger," and remained in that position until the train had reached a point 1 100 yds. ahead, when the movement of another lever, by the train passing over it, caused the signal in the rear to go to the "clear" or "off" position. This system failed and caused a serious collision, and was consequently discarded.

Another early form of automatic block working was introduced by Mr. Whitworth and patented by him in 1853, but a signal failing at Radcliff Bridge in 1859, and another at Clayton Tunnel in 1861, it was abandoned. The Clayton Tunnel failure caused the death of 23 passengers, and injuries to 176. It was considered that after this such signaling might be dispensed with.

So far as signaling in England is concerned, automatic signaling was never put into practical operation from the early experiments of Baronowski and Whitworth until the experiment on the Freshwater Railway, Isle of Wight. In this case the Board of Trade Inspectors ordered its removal.

The next and only instance of automatic signaling in England is that fixed on the Liverpool Overhead Railway on the Timmis system.

The Timmis System.—In this system there is at each station a home signal and a starting signal, the latter also acting as the distant signal for the station in advance, the block sections being short. These signals are worked electrically, and the conditions laid down by the English Board of Trade with regard to automatically working them were:

First.—That each signal must be put to the "danger" position by the train as it passes the signal.

Second.—That every train must always have behind it one signal, at least, in the "danger" position.

Third.—That when a train passes a signal, and automatically puts such signal to "danger," the passage of the rear vehicle of the train past such signal must be the only means of completing the electric circuit necessary to automatically lower the signal in the rear.

(In practice the passing of the rear vehicle of a train is made to put the signal immediately past to "danger" by breaking contact, and to lower the signal in the rear by making contact.)

The main feature of this system is the Timmis patent long-pull electro-magnet, those in use on the Liverpool Overhead Railway having, with a current of 5 ampères and 50 volts, a pull of 70 lbs. at 1½ ins. distance. These magnets are used to lower ordinary semaphore signals, but when the magnet has done its work and the armature is practically in contact with the core of the electro-magnet, the current is reduced to $\frac{1}{10}$, *i. e.*, 5 ampères, by automatically switching resistance into the circuit.

Supposing a train to be at Station A, between the home and starting signals at that place, the home signal will be in the "danger" position, and, assuming there is no train in the section ahead, the starting signal in the "safety" position. The train now leaves Station A for Station B. On passing A's starting signal, that signal will be put to "danger" and A's home signal lowered to "safety," which will

allow another train to enter Station A. A's starting signal being at "danger," this second train will have to wait at A until the first train has passed the home signal at B, the passing of this signal by the rear vehicle of the first train being necessary to complete the circuit through the coils of the special long-pull magnet operating the starting signal at A.

We now turn to the automatic system, which appear on the increase in the United States.

The Hall System.—In considering this system, the main feature of distinction between it and other systems lies in the fact that a substitute is used for the semaphore arm.

The consensus of opinion in all parts of the world on railroads which pretend to be modern approves the semaphore arm. It therefore becomes the duty of the promoters of a departure to give their reasons for the departure rather than argue the question.

The Pneumatic Automatic.—The question of expense is not one which comes within the province of this paper. This system seems to find favor with some of the railroads, but there would appear to be an unnecessary number of agencies employed to give the desired result. By agencies is meant different powers, such as steam or its equivalent, electrical, pneumatic. This much can be said in its favor, it incorporates the ordinary semaphore arm as its outward indication to enginemen. It is in itself a block system.

Although various other systems of automatic signaling have been tried, some of which are now in experimental operation in the United States, the author does not propose to treat upon them in detail, because automatic signaling cannot be the signaling of the future, in either the United States or any other country, from the simple fact that as soon as a switch is interposed, automatic signaling becomes at variance with the power or means of operating the switch. It is, of course, to be expected that the various stations and junctions will develop to the extent that switches and crossings must be operated from a central position in order that some system of interlocking control can be arranged between the several signals referring to the passenger lines and the conflicting switches; and as the switches cannot be operated by the automatic system, there must be two systems, if the automatic is to remain.

It would appear to be the cheapest and best system for the trunk

lines, at all events, to have their system of signaling of such a nature that one power may be subsequently employed for operating the switches and the other parts, when occasion demands it.

In considering the various systems which have been before the public, and which can fairly claim to be "lock and block" systems, we may mention, first, the Sykes system, which is the invention of Mr. William Robert Sykes, Sr., the Spagnoletti system and the Patenall system.

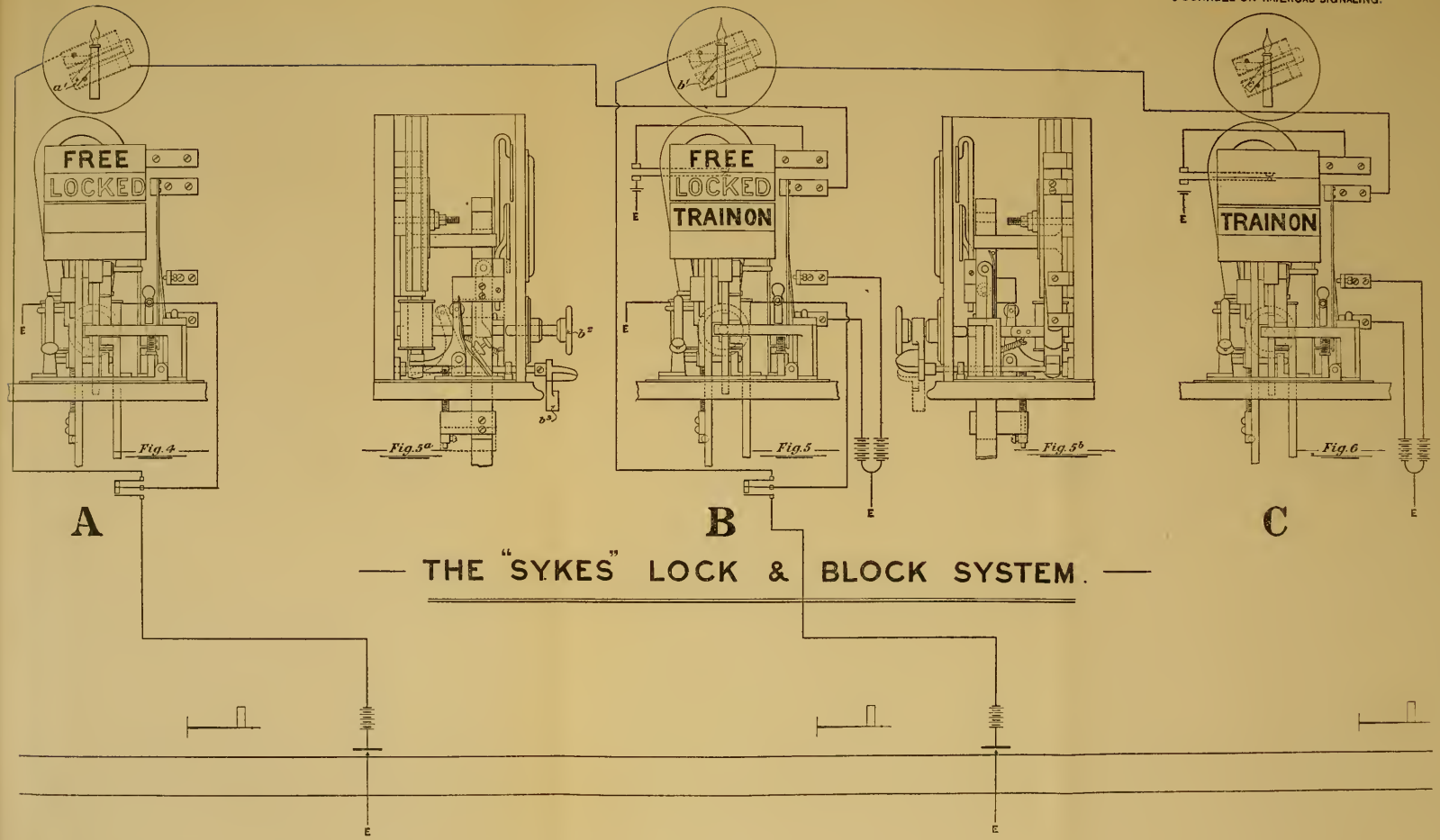
The system which has found the most favor, in fact which has monopolized the largest amount of installations of "lock and block," either in England or the United States, is the Sykes system.

It may here be mentioned that, taking railroads in all parts of the world, Great Britain not excepted, in the author's opinion the New York Central and Hudson River Railroad is the best signaled, and, consequently, the best protected, line in the world. This may appear a broad statement to make, but when it is considered that the New York Central and Hudson River railroad has, firstly, the interlocking system, and superadded to that, secondly, the union of the lock and block system (Sykes) over the majority of their lines, it completely bears out this statement. No line in Great Britain has so many lines of railroad protected by the lock and block system.

The author considers that great credit is due the management of that road for thus early appreciating the responsibility of a great corporation, and, doubtless, the American traveling public also fully appreciates the willingness of the company to safeguard their patrons.

A description of this system will serve to some extent to describe the systems also, so far as the results effected, of Spagnoletti and Patenall. There are certain features which in all these three systems, and certainly in the Sykes system, appear to be at variance with the condition of the line.

The Sykes (as used in England) system embodies in the instrument a miniature semaphore arm and tablets with the words "locked" and "free" and "blank" and "train on"; the normal position of the miniature semaphore being in the "safety" attitude, meaning "line clear," the dials illustrating in the normal position "locked" and "blank"; the word "locked" referring to the starting or sectional signal lever, and "blank" referring to the train movement as no



THE "SYKES" LOCK & BLOCK SYSTEM.

sanction given. Normally the miniature semaphore arm is maintained in the safety position by the current from a single cell battery.

The working under this system would be somewhat as follows: Referring to Plate LXIII, A, B, and C are three sections, and the three sections are assumed to be intermediate sections, neither A, B nor C being terminal, and, therefore, double instruments are shown at A and C, as well as at B. These instruments illustrate both receiving and sending portions.

Supposing B has given sanction to A, and the necessary instructions have been followed and the train to be traveling between A and B, B's instrument is locked and the two apertures in the instrument at B would disclose the word "locked" on the upper one, and "train on" on the lower one. Before B can lower his starting or sectional signal for the train to enter the section B-C, B by bell code will ask C to release his starting signal lever, C responds by plunging, which causes the upper dial at B to show "free," and the miniature semaphore arm *b'* to assume the "danger" position; it also causes the lower dial at C to show "train on." D then pulls over his starting signal lever, and this action causes the upper dial at B to change from "free" to "locked," indicating that the lever cannot be fully returned to its normal position, and also alters the circuit, so that, when the train passes over the treadle in advance of the starting signal at B, the lower dial at that place is changed from "train on" to blank, and B is then in a position to plunge again to A. The returning of the starting signal lever at B to the normal position intimates at A by the lowering of the miniature semaphore arm *a'* to the "safety" position that the line is again clear as between A and B.

In case B should from any cause whatever have to stop the train at his station after having received permission from C for it to enter the section B-C, and the train should eventually not enter that section, the instruments at B and C are made to resume the normal position by the use of a key which in the case of B does, electrically, what the passing of the train over the treadle in advance of B's starting signal would do, B being obliged to pull over his starting signal lever and insert the key to release the back lock from it, allowing it to be returned normal, which action puts his instrument into the normal condition of lever dial showing "locked," train dial blank and miniature semaphore arm *a'* at A at "safety." The use of the key at C only

mechanically releases his instrument and causes the train dial to show blank, the lever dial of course remaining normal showing "locked," assuming that no sanction had been given from D.

At this point it would be well to consider the statements that have been made with regard to this system, which would appear to lead the public to suppose that accidents are impossible with either of these systems. It is stated that "mistakes by the operators are rendered impossible, and any derangement in mechanism or misunderstanding in orders will never result in anything more serious than delay."

Take the case previously referred to, that C for any reason does not desire the train for which he has previously given sanction to A, and released B, to come into his section. In the usual course C bells back to B to cancel his signal, and himself cancels his own signal mechanically by the use of his key, thereby returning his own instrument to the normal condition in which he is free to accept another train from B and to perform any movements at his section that are desirable. B, on receiving intimation from C that C wishes the previous sanction to be canceled, acknowledges back on the bell that he has understood the signal and says that he will cancel. Meanwhile some other duty takes his attention, and he does not cancel; a train arrives at B's starting signal, and B, having already lowered his starting signal, the train enters the B-C section. An interval of time elapses during which C has finished his shunting, or other movements, and B now asks for sanction to send another train, and C gives him such sanction. The sections are short. B may suppose that the train he had previously sent (unknown) to C had arrived at C, passed out of C's section and C given sanction for another train; B therefore allows a second train to enter the B-C section.

Misunderstanding between B and C signalmen there certainly is, but no tampering has taken place with the instruments other than is common and usual by the insertion of keys for the purpose of cancellation, and yet two trains are in C's section at one time.

There is a still more serious objection to which all the lock and block systems previously mentioned are open, and that is, that if a train has arrived, say on the west-bound line, and it is shunted through a cross-over road on to the east-bound line, no proper means are provided by which the east-bound line is blocked. The previously described system of cancellation has to take place to free the west-

bound line, to allow the signalman to accept a train from the rear. The signalman can, under these conditions, receive a train on the eastbound line from the section in the rear although the line is blocked by the previously shunted train which may be standing between the home and starting signals. This is the most common form, so far as experience in Great Britain is concerned, of serious accident which has occurred, such as that at Norton Fitzwarren.

The normal condition of the line in the Sykes system is considered "safety."

So far as the majority of railways in Great Britain is concerned the normal condition of a line is considered as "not clear," and it requires sanction from the cabin in advance to place the line in the "clear" condition.

In the Sykes system the miniature semaphore is normally in the "safety" attitude, and it appears to be a curious anomaly that when sanction is given by the cabin in advance, the outward indication of that sanction consists in raising the miniature semaphore from the "safety" attitude to the "danger" attitude. The raising of this miniature semaphore from "safety" to "danger" in this instance is to indicate that the line is "clear," but taking the normal condition of two sections, and the section in advance wishes to intimate to the section in the rear that he is not free to accept a train and does not wish to be asked for sanction, he moves his switch b^3 locking the plunger b^2 at B, and by that action also raises the miniature semaphore arm a^1 at A from "safety" to "danger." We therefore have the action of this arm moving from safety to danger, indicating contradictory meanings. In one case it means that the line is "clear" and in the other case it means that the line is "blocked."

Spagnoletti's System.—The main features of difference between the Spagnoletti system and the Sykes system consist, firstly, there is no miniature arm, and consequently, secondly, no necessity for a permanent current which in the Sykes system is holding the miniature arm to the "safety" attitude; and, thirdly, there is no back lock on the starting signal lever preventing its full return.

The system of cancellation in the Spagnoletti system is the same in result, but different in means. A glass case is provided in which is enclosed a press button, and for the purposes of cancellation the glass must be broken and the button pressed; of course, once the

glass is broken the button may be pressed any number of times for the purposes of cancellation.

The same freedom is allowed so far as shunting a train from one main line to another is concerned.

Patenall's System.—It is perfectly true, as set out in the preamble to the specification of this invention, that "This system embodies some of the generic features of what is commonly known as the Sykes system." It might probably be more correctly put by stating that it embodies nearly all the generic features of the Sykes system, these features including both those that may be good and those that the author considers defective.

The main difference consists, firstly, in avoiding the anomaly of the miniature arms in the Sykes system by having no miniature arms at all, the same as the Spagnoletti system, and consequently not having any permanent current, and, secondly, the facility claimed of being able, having once received sanction from the cabin in advance, to manipulate the starting signal lever backwards and forwards any number of times.

With reference to the first difference, if the switch b^3 in the Sykes system be moved to lock the plunger it would place the miniature arm at the section in the rear to "danger" by cutting off the current, and if this were treated as the normal condition the advantages in the Patenall system of not having a constant current on, would be obtained. Under these conditions (Sykes system) A would ask for sanction to B, B would remove the switch b^3 from his plunger b^2 which would electrically replace the miniature arm a' at A to the "safety" attitude.

With regard to the second difference between the two systems, so far as the author can understand the object in being able, in the Patenall system, to replace the lever completely to its normal position, is simply to release the interlocking of any switches in the rear and not to require a second sanction from the cabin in advance to pull the starting signal off when the train in the rear section is required to proceed. It may be observed that, if the Sykes system is carefully considered, the full advantage of being able to put the starting signal arm to "danger" in the face of the driver, to prevent him going into the next section, is allowed, as the starting signal lever can be returned almost to its normal position to allow the signal to go fully to

"danger," and, although in the Sykes system the interlocking may be retained on the conflicting switches in the rear, yet if the interlocking notches on the starting signal lever were made wider, the full privilege of taking the interlocking off the conflicting switches would be allowed without departing from the Sykes system by making any alteration which would be unauthorized.

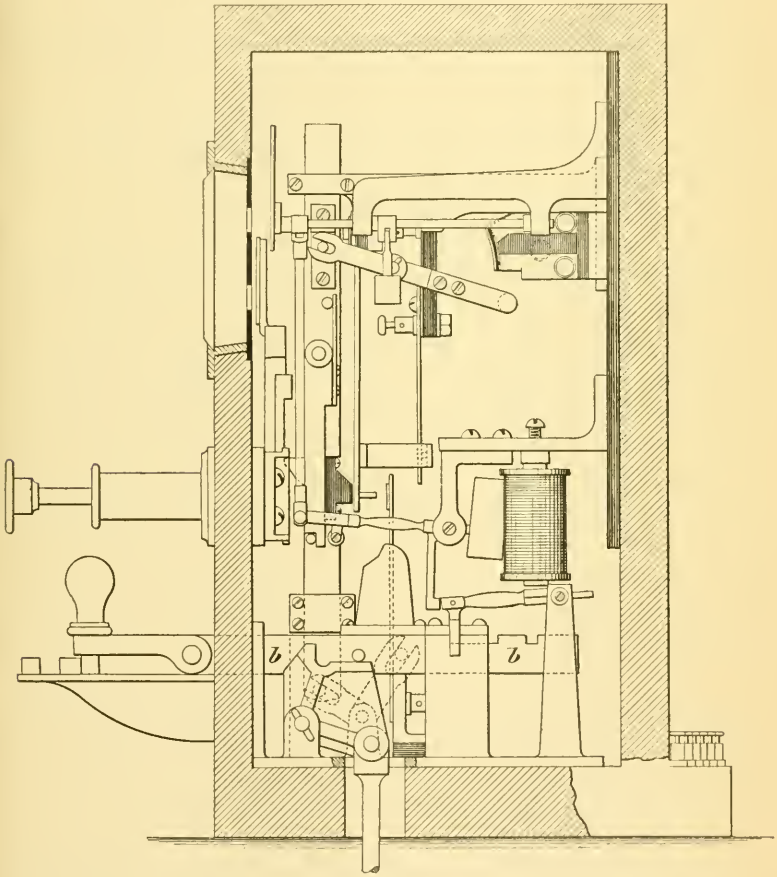


FIG. 1.

The material difference in the manipulation of the two systems (Sykes and Patenall) lies in the fact that in the Patenall system the signalman in the rear has more to do than in the Sykes system; he has an initial movement partly withdrawing the slide *b* (Fig. 1). This action brings the releasing coils into circuit with the plunger of

the section in advance, the slide *b'* is released so that it can be fully withdrawn, this action mechanically releases the starting signal lever, and that signal so released is free to be operated backwards and forwards any number of times; but the signalman at this post cannot give sanction for another train to approach him from his rear until the previously accepted train has passed over the treadle in advance of his starting signal.

In considering this subject, there are a few points which the author considers essential in any lock and block system. Firstly, the present facility of cancellation should be abolished. When once block sanction has been given to the rear section, the only legitimate release should be the fulfillment of the sanction. Secondly, when a train, or even any pair of wheels, is occupying a section, the obstruction should be got rid of before sanction can be given to the rear. The action of clearing the line of whatever is fouling it should release the plunger or its equivalent in its own section, thereby allowing sanction to be given to the rear. Thus, if any vehicle is moved from one main line to another, the road it leaves is automatically freed, and the road it enters automatically locked. Those who have not had the benefit of living in this country in personal contact with the railroads have therefore had little experience of the operation of electric track circuits; yet, without entering into a discussion as to the merits or demerits of the track *versus* the wire circuit system, it may be assumed that the track system should be included in this paper, from the simple fact that it seems to meet with considerable favor from certain of the railroads in the United States.

There are many features which a perfect track circuit system would obtain over the wire system, chiefly in reference to shunting operations from one main line to another, from main lines to sidings and *vice versa*, and the breaking away of coaches, and generally any obstruction on the metals.

The third essential is that a train on entering a section should automatically place the sectional signal in the rear section to "danger" independent of the operator, and it should so remain at "danger" until the train has entered the section in advance. Thus take three sections, A, B, C, a train entering the A-B section should put the "danger" A's starting or advance starting or home signal, according to the installation, and it should remain locked at "danger" until the train

has entered the B C section. Through the courtesy of a member of the joint committee on interlocking and block signals of the American Railway Association, the author had given him a copy of the minutes of proceedings of their last meeting held at the Hotel Brunswick, New York, in April last.

This paper is already longer than the author originally intended, but there appears to be such a diversity of opinion in the Association in relation to the use of a distance signal; and further, a distinction suggested to be drawn between what is called the telegraphic block system and the controlled manual and automatic block systems, in relation to distance signals, that it would occupy too much space here to discuss the questions raised; but in any discussion which may follow the reading of this paper the author respectfully suggests that these questions might be included.

Single Line Working.—Any paper on block working is certainly not complete without an exhaustive treatment on this subject. Correct block working on single-line railroads is far more essential than on double-line railroads, for in the former all forms of collision are likely to occur. The subject is, however, too extensive and important to be lightly dealt with now, and the author must leave it to others better entitled to describe its operation than himself; or leave it for another occasion, when he might venture to set forth a few points worthy of discussion.

Signal Replacers.—In the majority of the systems of "lock and block" which are now appealing to the public, some system of automatically replacing the section signal in any section to "danger" on the passage of a train out of that section, is considered essential.

It is, of course, understood that the idea of automatically replacing the sectional signal to "danger" is comparatively old, and that there have been many schemes before the railways for effecting this, but, so far as the author is aware, all the schemes are open to the objection that the engagement between the two portions of the upright rod to the balance lever and the arm is made and maintained by the electric current, and consequently there is, first, a sudden wrench on the armature when the signal is pulled off, and during the time of remaining off a steady strain (more or less according to the design) on the armature. There is a considerable strain on the Lattig, less in the Hambay, and less still in the Coleman,

but, however little the strain on the armature may be, the author submits that the principle in all of these is wrong. The electric current should only be used as the means of engaging the apparatus, and the strain caused by pulling the signal off and maintaining it in that position should be borne mechanically.

For the better understanding of the differences between the methods of signaling trains with the single-needle instrument and the semaphore and similar instruments, the author proposes to follow, in each case, the signaling of an express train through a block section.

Taking the case of the single-needle instrument first, and assuming two sections, A and B, and a train approaching A from the rear: A rings once on the bell to call B's attention, B intimates he is attending by repeating the signal to A; A then gives what is commonly known as the "be ready" signal, four beats on the bell, which B acknowledges by repeating. A intimates the acknowledgment is correct by giving one beat of the needle to the right, and B then pegs the needle to "line clear." When the train has passed A's post and is about to enter B's section, A again calls B's attention by one beat on the bell, which B acknowledges by repeating as before. A then gives two beats on the bell to B, indicating "train on line." B repeats and unpegs the needle, A acknowledges correct repetition by one beat of the needle to the right, and gives the descriptive portion of the "train on line" signal, two beats of the needle to the left. These are repeated by B, A acknowledges correct repetition by one beat of the needle to the right, and B then pegs the needle over to "train on line." When the train passes B with tail lamp or board on the last vehicle, B calls A's attention by one beat on the bell which A repeats, B then unpegs the needle and gives the "train out of section" signal, two beats of the needle to the right, A repeats this signal, and B acknowledges the correct repetition by one beat of the needle to the right, and then allows the needle to resume the normal (vertical) position.

Taking now the case of semaphore and other similar instruments and the same conditions as regards sections, and a train approaching A: A will give the warning (be ready) signal to B on the bell, two beats, pause, two beats; this is acknowledged by B by one beat on the bell. B then plunges, which raises the miniature semaphore at A, and indicates at B "train on." When the train has passed A's post and is about to enter B's section, A gives the "departure" (train on line)

signal, two beats on the bell, and B acknowledges this signal by one beat on the bell. When the train passes B with tail lamp or board on the last vehicle, B gives the "all clear" (train out of section) signal, three beats on the bell, and A acknowledges it by one beat on the bell, the miniature semaphore arm at A is caused to return to the "safety" (normal) position by the putting back of the starting signal lever at B, which can only by done completely when the train has passed over the treadle in advance of the starting signal at B.

Although block signaling with the semaphore instrument is simpler than with the single-needle instrument, block signaling with the latter is not so complicated as the description would make it appear, and it is incomparably better with regard to the possibility of mistakes being made in the interpretation of the signal; and where it is necessary to indicate the route and description of trains, the single-needle instrument, in combination with the bell, lends itself to the purpose much better than the semaphore and similar instruments; in fact, it is within the author's knowledge that these instruments have to be supplemented with single-needle instruments to be used for the purpose of describing trains alone; and as the opinion of the majority in England favors the use of the single-needle instrument, which is conclusively proved by its adoption by the most important railways, probably it is only necessary to adapt it to a "lock and block" system to make such system the "lock and block" system of the future. Upon this phase of the subject the author cannot, at present, enlarge.

DISCUSSION.

Desmond FitzGerald, M. Am. Soc. C. E.—One question; you have been over a large number of railroads in this country; would you mind saying where you consider the best combination system in this country is found?

Mr. O'Donnell.—The best illustrated is on the New York Central road. A combined use of the block system and the interlocking system is necessary, and the best system is a union between the two. There is only one road in this country that has the interlocking and the block in combination, that is the New York Central.

Foster Crowell, M. Am. Soc. C. E.—I would like to ask Mr. O'Donnell in regard to systems other than those he has described,

which are all based on the principle of visual signals. There are some systems, or some devices, coming into notice in which the visual signal is entirely dispensed with.

Mr. O'Donnell.—I gather you refer to the Kinsman block system. That proposes to entirely eliminate signals of all grades, but relies practically on the fact that, while there may be a signal directing a movement, if the train passes it at "danger," it is automatically stopped. That necessitates an addition to the locomotive. We have had trials of similar systems and many endeavors to have them adopted, but I do not think you will find superintendents in this country ever take sufficient interest in signaling to alter their locomotives.

Mr. Crowell.—The system is on trial, in regular service, on the Chicago, Milwaukee and St. Paul Railroad, and possibly some of the officials of that road are here and can give us some information as to the success of the operation. The attachment which Mr. O'Donnell has alluded to as being necessary to the locomotive, is of such trifling and inexpensive character that it does not militate against the system in the least. There may be other reasons.

Mr. O'Donnell.—There is one other which occurs to me, and that is, if you rely absolutely on some such system and the engineer of the train comes to disregard his signals, expecting that even if he does pass them at "danger" he will be stopped, if a collision should occur, it becomes a serious question; the signal becomes under those conditions of secondary importance.

Mr. Crowell.—I am not here in any way to represent any system or theory, but I should like to point out that Mr. O'Donnell has emphasized the importance of a system of signals not based on color nor on form, but on position, so as to avoid, as far as possible, any likelihood of the man running the engine either failing to see the signal or misinterpreting it.

His failure to see the signal may be due to his eyesight, or to fog or to other causes. If he fails to see the signal, the signal might as well not be there. Some very disastrous accidents have occurred in this country, due to the impossibility of seeing a visual signal. I understand that there has been an impetus given to the effort to supply the place of a visual signal, and the automatic Kinsman system and other devices have been suggested on that account.

The Kinsman system, in addition to affording a means of stopping a train in case of the disability of the engineman to see the signal or to comprehend it properly, has the facility for doing more than merely providing block signals. In addition it also operates in connection with open switches, misplaced or unlocked switches, or partly open draw bridges—all track interruptions, in fact, are taken care of by the Kinsman system—so that, not only alone, but also as an auxiliary to any

other system, it would have uses. It is a system in its infancy, and it is so startling in its departure from the old preconceived notions that the engine driver must see the signal, that at first it does not recommend itself. The practical application of any system is the test. The system applies both to double-track and single-track roads, and there has been found great difficulty in the way of applying the block system to a single-track road with visual signals. I here want to thank Mr. O'Donnell for the comprehensiveness with which he has outlined these different systems. The ability to use visual signals with the Kinsman system is quite evident. Mr. O'Donnell has called attention to the fact that in case visual signals were used in connection with the Kinsman system, the engine driver might get careless; but I think experience proves the reverse.

Mr. O'Donnell.—I would like to ask Mr. Crowell one question. Does the Kinsman system provide for the operation of the distant signal? It is the only signal the driver can pass both at danger and safety. I understand the Kinsman system stops him at danger.

Mr. Crowell.—The Kinsman system stops him without reference to the position of the distant signal; in other words, there is a multiplication of signals, and the principle of the connection with the distant signal is not contemplated. I, perhaps, am going a little too far. I ought not to say anything which represents the Kinsman system. I am only giving my knowledge of it. The same principle can be applied with an indicator signal, and the wiring of the Kinsman system could be extended to the distant signal as such if desired. There is a modification of the system by which it can be known to the engineman whether he is stopped in advance or by an overlapping danger from the rear. On a single-track road he thus knows whether he is stopped from a danger ahead or from behind, which is quite important.

The question you have asked, so far as I am able to answer it, is very simple. The Kinsman system, in itself, does not necessarily involve the use of the distant signal at all; but if it is desired, the application is easy by a simple extension of rules.

Mr. O'Donnell.—If the distant signal is accomplished, it seems to be the rear home signal. You may accomplish the signaling and treat the distant signal as a home signal, but that does not allow the man to creep up to the home signal and know what the condition of the line at the home signal is. I have not studied the Kinsman system. You raised one question in connection with single lines.

With the tablet or electric train staff systems, the withdrawal of either the tablet or the staff from the instrument automatically breaks down the block system, but I have for some years repeatedly pointed out that the Sykes lock and block system, if properly carried out, is just as good on single-track roads as on double-track roads, the idea being to maintain a space interval between trains absolutely. If

it is considered that the traffic would be too much hampered on single-track roads by preventing a second train in the same direction until the first train had cleared the section, then a permissive staff system could be employed, which would allow one or more trains in the same direction, but no train in the opposite direction until the last train has arrived at the section to which it is running.

There are certain conditions which would be necessary in carrying out this system, but it is very cheap, easy in working, and a complete block system, and hedged round with conditions by which a great amount of safety can be obtained. The head-on collision is absolutely prevented, which, after all, is the most serious form of collision, and that more likely to happen on single-track roads than on double.

E. E. Russell Tratman, Assoc. M. Am. Soc. C. E.—What does Mr. O'Donnell think of the Black system on the Manhattan Elevated Road, which seems to be practically the same as the Baronowski system (1858) ?

Mr. O'Donnell.—I am not connected with any system, but I have fundamental objections to all mechanical systems. The Black system is merely a mechanical automatic signal. I have seen two trains many a time on that road when there was no space interval except a few yards between them.

A Member.—I presume that lack of space was due to not carrying out the rules of the system.

Mr. O'Donnell.—Possibly. The Manhattan Elevated Railroad may be put in the class of railroads which has no margin of space, and so frequent are the trains, possibly they must disregard a block system ; certainly a block system is not operative there.

Mr. Tratman.—Do they not still have in England a common practice of giving a "section clear, but station blocked" signal, implying that the engineman may run as usual over the block or section, but with the expectation of finding the station signals against him, protecting a train in the station, and thus making a permissive block. In such case does the signalman give any special warning to the engineman? I understand that this rule has led to several accidents.

Mr. O'Donnell.—He is supposed to caution the engineman, but the rule you quote is frequently condemned by the Board of Trade and is very misleading.

Mr. Tratman.—Has not the Board of Trade power to prohibit such practice ?

Mr. O'Donnell.—I believe it has, but it hesitates to exercise its power unless authorized by Act of Parliament.

H. G. Prout, M. Am. Soc. C. E.—There is a point raised on page 436 of the paper that is occupying a good deal of the attention of American signal engineers. That is, with reference to the normal danger position of the automatic signal. It is a fundamental principle

in railroad signaling that the normal position of the signal should be danger; the absence of a signal should be a danger signal; the positive signal should be a clear signal. If there is no signal, it should mean danger. But in the introduction of the automatic system on the American railroads, we have run against the difficulty of using the normal danger position for the signal. One, at least, of the companies introducing the automatic system is now putting in its signals to be operated in that way so that they stand normally at danger; but I understand that railroad men, particularly in the West where they have long lines of unobstructed view, base their idea of the automatic signal on the ground that as the engineman approaches the signal, which he may see for a long distance, if it is standing at danger, he does not know whether it is going to be cleared or not, and he does not know whether to reduce speed or not, and this uncertainty will cause delays. I can conceive that it would be an inconvenience for them to abandon the normal clear position; but it seems to be a vital principle in signaling that the normal position of the signal should be at danger, and it would be interesting to hear some discussion on this particular point. Mr. O'Donnell has, I have, no doubt, very decided views on the matter. Mr. Wallace is here now and has had considerable experience with automatic signaling, and he might tell us something interesting on that point.

John F. Wallace, M. Am. Soc. C. E.—I did not come here intending to discuss this paper. This is a paper prepared by an expert in signal engineering, and we have very few in our society. I do not presume to be one myself, although I have had more or less to do with signals. Mr. O'Donnell takes practically the English standpoint in his paper; any answer to him should be carefully prepared, but I am willing to give, as suggested by Mr. Prout, a description of the signal system on the Illinois Central Railroad which may be of interest to you in this connection.

The road embraces 3 690 miles of line, and of course the larger part of it is composed of branches and outlying lines that a railroad company cannot afford to signal, but we have a modified telegraph block that extends over the whole system. It is what is called the Harrington system; that is, double semaphore arms located at all telegraph stations and are operated by the telegraph operators. Those arms are held at danger normally; when a train approaches the station, and the engineer sees both arms at danger, the engineer calls by whistle for his signal. If the block is clear or no orders await the train, the operator lowers the arm and the train proceeds. On this portion of the road we have no difficulty in reference to the point that Colonel Prout raised. Some of our limited trains run at 40 or 50 miles between stations, and there is no slacking speed for this reason. In the Chicago terminal district, however, a part of which consists of eight tracks,

part of six and part of four, down to a double-track system, we use what is known as the Hall automatic. One district is divided up into two lines for local suburban traffic, the stations being 2 600 ft. apart. Two tracks are given up to through passenger service, the blocks being from 5 000 to 5 600 ft. apart, two to freight and two to fast express suburban service. All junction points are handled by interlocking systems, connected with the automatic block systems. On this section our signals are not operated on the normally danger plan, for the reason that Colonel Prout spoke of.

We desire these trains to run at high speed, and sometimes two or more signals can be seen ahead of the train, so that it would be liable to cause our engineer to diminish the speed of trains if they were operated on the normal danger system. The signals, however, are so fixed and regulated, that should any blockade or failure occur they would go to danger automatically. That is, the normal position of the signal is at danger, but it is held clear by the electric action. Should the electric action fail, or should a switch be left open, etc., the signals would come to danger automatically. We have operated this system for over a year. During the World's Fair period we handled at the terminal stations from 900 to 1 000 engines in 24 hours. We carried in six months 19 500 000 people in round numbers. During that period we had no failures, in the sense that a signal ever showed clear when it should show danger. We did have failures in the sense that through the breakage of the wire or through a short circuit the signals would occasionally go to danger when they should have showed clear. When the system was installed the track circuit was not entirely perfected, but the railroad company had the option of changing to what is called the "track circuit," if they desired. Since that time it has all been changed to track circuit. In that system an open switch between Signal 1 and 2 would change the signal to "danger." The closing of the switch automatically will clear the signal, and in order to prevent the opening of the switch after the train has passed into the block, the switch is provided with indicators and bells, so that after the train has passed into the block the bell begins to ring, and rings until the train has passed out of the block.

This system has given us perfect satisfaction, and has satisfied not only the engineering department, but also all the transportation officers who have used it.

H B. Seaman, M. Am. Soc. C. E.—Has Mr. Wallace any electric trolley road parallel to his line?

Mr. Wallace.—We have two crossing our line, but during the term before we put the signals into active service we worked them under cover. That is, the disks were shaded, but a small aperture was left so that the signal engineer could see the working of the signals. During that time we had one failure, due to the ground circuit. As

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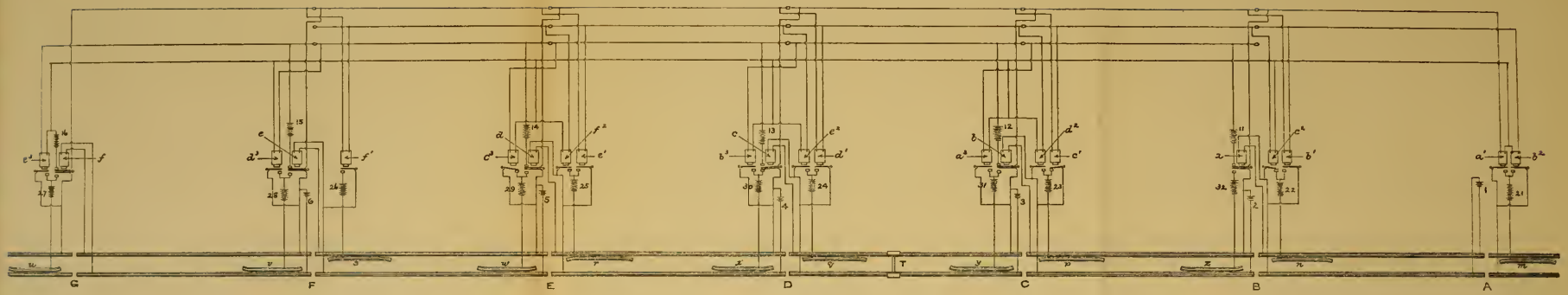
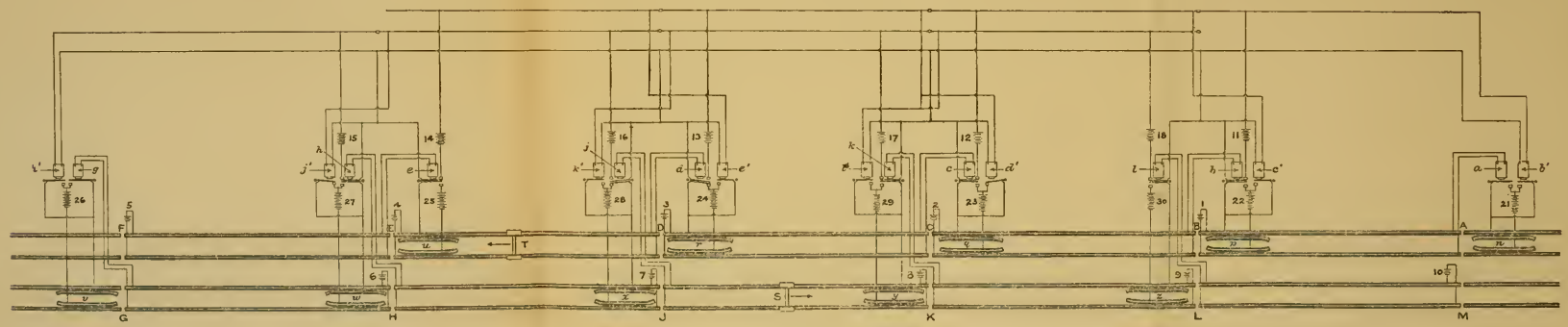
ARRANGEMENT OF CIRCUITS FOR SINGLE TRACK ROAD.



ARRANGEMENT OF CIRCUITS FOR DOUBLE TRACK ROAD.



I understand the case, as reported to us by one of the signal engineers, the circuit in the rail was very slight and the leakage of the ground current from an electric road crossing our rails caused a short circuit, and we had considerable trouble until we cut out a short section of track for about 25 ft. on each side of this crossing and connected the rails by wires past this crossing.

In reference to the disk form of signal which Mr. O'Donnell mentions, at the last meeting of the Railway Association an effort was made to establish the semaphore signal as the standard, excluding all others. The Railway Superintendents' Association, I understand, decided that either form was allowable. The reason the Illinois Central adopted the disk signal was this—we found it necessary for practical, as well as economical, reasons to use an automatic signal. We had to choose between an automatic pneumatic, controlled by one company, and the disk controlled by another. The automatic semaphores applied to block signals require a great deal of care. We chose the disk in the first place because it was enclosed in a case, it was protected from the air and operated by gravity, and it was considered that it would give less trouble in maintenance, and we saw nothing that would cause it to go to safety when it should show danger. Our interlocking plants are situated at junction points and connections, and the tracks protected by semaphore signals and derails. An engineman running by these signals is immediately derailed. We desire that the signals used in any way permissively should be of a different character from the absolute stop signal of the semaphore.

I would like to say one word with regard to the Kinsman system. It is this. The main objection that I see to it, from a practical standpoint is, while the amount of money that would be necessary to expend if it were affixed to one individual locomotive is small, yet when you attempt to apply it to a line it would be a matter of great expense. Take our road. On our terminal line we have engines that come over the Michigan Central and the Big Four road. We are liable to bring engines into our general repair shops for repair from all the outlying districts. In order to use a block system of that character we would have to have not only all locomotives in daily use on this section provided with it, but also all the other locomotives; and in a busy terminal like Chicago, there is a liability at any time to have freight and other locomotives running over those tracks belonging to any railroad entering the city. That, it seems to me, is the greatest objection to the system.

A Member.—I would like to ask Mr. Wallace if they had any trouble with their disk signals, due to snow storms and sleet?

Mr. Wallace.—During last winter we had a great many storms, and there was only one time that we had any trouble from sleet.

A Member.—Did it not obscure the color?

Mr. WALLACE.—No, not entirely.

Mr. O'DONNELL.—There was one question which Mr. Prout raised and which Mr. Wallace corroborated ; that is, with reference to the use of the normal safety position of the system on the Illinois Central. The point was raised that drivers, if the position was "danger," might possibly hesitate as to whether it was to be drawn off and would not know whether to slacken speed. It occurs to me that that might be overcome if you overlap your sections, make Section 1 automatically lower Section 3; when he comes to Section 3 he is held, and so 1, 3, 2, 4 throughout the line, the signal to lower before he comes into the section.

There was one question which Mr. Wallace raised, which was, as he stated, the question between the promoters of one form of signal and the promoters of another. Of course, there are other signals in the market which have the normal danger position and the semaphore arm, as on the New Jersey Central to-day.

Mr. TRATMAN.—I do not see any reference in Mr. O'Donnell's paper to the Mozier system, which is in use on about 1 000 miles in this country, and differs from most other manual systems in being controlled by the train dispatcher. Thus, while in ordinary systems the orders are transmitted from one block signal tower to the other (as *A* to *B*, *B* to *C*, *C* to *D*, etc.), in the Mozier system they are transmitted from the dispatcher's office to the operator in each tower successively (as *X* to *A*, *X* to *B*, *X* to *C*, etc.).

Mr. O'DONNELL.—My paper is already too long, and if I were to include all the various systems which promoters have introduced, it would be a considerable book.

Mr. Wallace mentioned the semaphore arm outside of the block system, which is operated manually.

Mr. WALLACE.—The Harrington system. It is a combination system, so far as dispatching the trains is concerned.

Mr. O'DONNELL.—The New York Central, which is operated by the operator, has the manual signal, which is in front of him.

Mr. WALLACE.—Yes.

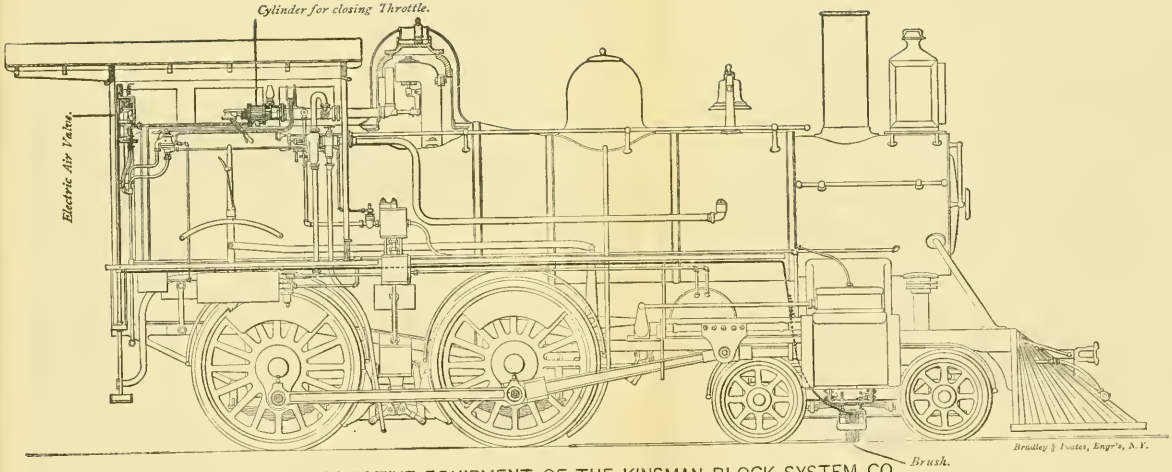
Mr. O'DONNELL.—The fact of his being a train dispatcher does not interlock the two.

Mr. WALLACE.—There is no interlocking of signals in this system.

J. RAMSEY, Jr., M. Am. Soc. C. E.—He may tie his signal down. It is simply the operator giving a signal for a train to enter the block between his station and the next.

Mr. O'DONNELL.—Unfortunately, the signal is placed in the middle of the section.

Mr. RAMSEY.—Mr. Wallace referred to the action of the Railway Association. The largest portion of the discussions at the April meeting was on the signal question. The Association idea was simply



LOCOMOTIVE EQUIPMENT OF THE KINSMAN BLOCK SYSTEM CO.

to adopt three general divisions of signaling; one, the station signaling, which we have just referred to; the other a manually controlled signal, and the third class the automatically controlled signal. A large majority of the railroads voted in favor of the semaphore arm as against the disk signal. Further than that they did not go. They referred the whole question back to the committee, and there the matter remained.

One of the questions was as to the proper light for safety, whether it should be white or green? If the red lens is broken, the safety signal is shown (no matter what block system is used), so long as the white light is used at night, so that there may be a safety signal given when the danger signal is intended. On account of determining the proper color for safety signal more than anything else, the whole matter was referred back to the committee.

Mr. O'Donnell.—There has been a great deal of discussion in relation to the colors, but in the British Board of Trade it has been decided that white is the danger signal. In this country you have adopted the green for the danger position, and, therefore, you have to find a substitute if you put green as the "all-right" signal.

Mr. Ramsey.—White can be used as a caution signal.

Mr. O'Donnell.—No, white should be used as danger. Perhaps Mr. Crowell will give us some further information about the Kinsman system.

Mr. Crowell.—It will give me great pleasure to do so; and first it may not be out of place for me, in as few words as possible, to define the Kinsman system. It is a system of automatically stopping a train in the face of danger through the agency of electricity. The cause which may stop a train may be an approaching or standing train within the block, or it may be a train or an engine or a car on the track not within that block, but within an adjacent block or a block removed two spaces away, or as many spaces as may be desired. The communication between the block and the train to be protected is by wire connection, and may be of any convenient length; usually it divides the road into blocks of track, protecting every alternate block as well as the adjoining block; that is, each block is protected from the second block away, either before or behind, and also from the adjacent blocks (see Plate LXIV). The protection is, 1st, from a standing or moving train on the track; 2d, from an open drawbridge, or any break in the continuation of the rail; 3d, also from any open or unlocked switch, for the wiring may be so arranged that unless the bar which locks the switch is completely closed, the operation of the system is just as perfect as if the switch is open. The system is based on an original departure from all systems of visual signals. In a proper sense, it is not a signal system at all, although it can be worked in combination with a signal system and signals can be used. It operates as follows:

The train, in approaching a protected point, passes over and in contact with (see Plate LXIV) two ordinary guard rails, which may be set at the regulation distance from the main rails. The locomotive is provided with a contact brush (see Plate LXV), which travels within the flangeway of the forward truck. On reaching a contact point, if the guard rails are energized by an electric current, the communication between the guard rails and the locomotive is set up and the operation follows. If there is no energy in those guard rails there is no operation whatever of the apparatus. To energize those guard rails a current comes from a relay battery, which is placed in a convenient position near the contact, usually so that the connection between the relay and that point is a very short one; the connections from battery to contacts are protected, and, in order to guard against the accidental interruption of the relay, the latter may be in duplicate or in triplicate. The relay is arranged so that the energizing current proceeds from the battery to the guard rails whenever an armature is dropped in the battery box; that armature is connected with the track circuit and dropped by short circuiting or by disruption of the circuit. Provision is made for two automatic actions of the devices before the "section" in which the cause of action exists is reached, thus always preserving one clear "section" of track between an approaching train and the point of actual danger. If there is an obstacle on the track, any break in the continuity of the track or any other cause of danger, the armature drops in the battery box, operating the guard-rail circuits in adjoining sections. When the energizing current is in force, the brush attached to the locomotive and moving in the flangeway comes in contact with the guard rails, and the current passes through the wiring of the locomotive (see Plate LXVI) to an electric air valve placed in the cab. When the energizing current reaches it, the valve is opened and communication established between the train pipe of the ordinary air-brake apparatus, and a cylinder (Plates LXVI and LXVII) placed around the valve stem which controls the throttle of the engine. The admission of the air to this cylinder starts the valve stem, and, immediately after starting, communication is made with the open air, so that the automatic action of the brake is at once set up. In other words, the instant that the contact brushes on the engine pass the contact position, the current shuts the throttle and sets the air brake. No change has been made in the usual methods of operating the steam or air valves; in fact, if the apparatus was enclosed no change would be noticeable to the engineer until such time as he failed to see and obey the danger signal or other cause which required a reduction of speed or a full stop. Neither does this arrangement prevent his obeying a visual signal in the ordinary way, should he have occasion for so doing.

The operation that takes place in the cab is precisely that always

PLATE LXVI.
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CROWELL ON RAILROAD SIGNALING.

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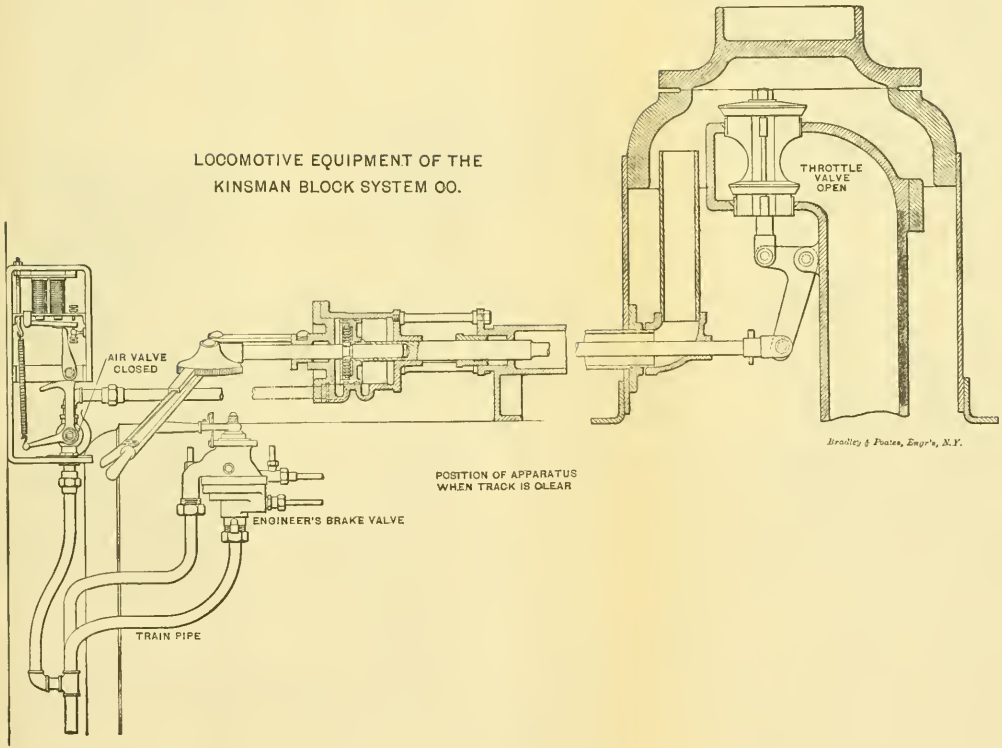


Bradley & Peates, Engr's, N.Y.

performed by an engineer when he "slows down" or makes an ordinary stop, no more, no less; that is, the shutting off of the steam by closing the throttle valve and the setting of the air brakes by releasing the air from the air-brake system.

However, should it be inconvenient for the engine driver to stop at that point, or should it not be required of him to do so, or should he wish to treat this stop as a distant signal and run to the end of his block before coming to a stop, he can immediately open the throttle again and release the brakes.

The means by which that is brought about involves only a very simple addition to the locomotive. A new engine, of course, can be built in such a way that the appliance can be in any desired form; but on an old one a small cylinder is put on the end of the boiler, projecting out 12 or 14 ins. to the rear (see Plates LXVII and LXVIII), surrounds the lengthened-out valve stem. The usual throttle lever is used; the throttle lever, however, is connected to the stem through the medium of an automatic clutch, so that the valve stem will work without carrying the lever with it in case of an energizing, but the lever always will move the valve stem. The apparatus, therefore, which is used on the engine, is extremely simple and inexpensive; it is not subject to great wear and will last a long time. The additional cost of fitting up a locomotive with a cylinder is small. Plate LXVIII is a view of a working model showing locomotive equipment in actual relation. *A* is the throttle-stem cylinder, *B* represents the boiler end, *C* is the electric air valve, *V* the ordinary engineer's brake valve, and *T* the throttle.

In this way I reply to the objections raised by Mr. Wallace. Also as to the statement that were the system used on one line it would be an embarrassment not to have it applied to foreign locomotives that might pass over that line, the answer is that the expense is light enough to make that objection unimportant. No more objection attaches to that than to the different couplings now in use. For instance, our train from New York over the Lehigh Valley Road had cars with one style of couplers; on some of the cars from Philadelphia there was another style; and still another is in use on the Reading road, so that a change of coupler heads was necessary *en route*. That is an illustration that that kind of an objection is not a serious one if you are trying to get an ideally perfect system.

The application of the Kinsman system to the block system of stopping trains is therefore possible, whether you use it for the absolute block, connecting two successive blocks, or intermediate blocks, or blocks any distance apart. If it is desired to maintain the visual system in connection with it, it is quite possible to adopt the signal too. If it is desired to retain the principles of home and distant signals, the same arrangement is possible. It can accomplish all that the visual

system accomplishes, and it can accomplish also the protections which the block visual signals cannot, that Mr. Wallace has referred to.

The absence of the necessity of looking out for a signal is a startling one when we first regard it, but when we consider that the most prolific cause of danger and accident is the failure to observe a signal, it is a recommendation for a system that it can be dispensed with.

I will only add that the Kinsman system has passed its experimental stage and has been in successful operation on one of the divisions of the Chicago, Milwaukee and St. Paul road for a number of months. I am not in any way connected with, or responsible for, the system. I, however, superintended, as consulting engineer, the practical tests of the system in its inception and have watched its results with great care.

Mr. O'Donnell.—I do not propose to reply in detail now to Mr. Crowell, because I think it would be better to do so when the matter comes to me in regular course, as the meeting is now already rather prolonged. But there are one or two points which Mr. Crowell has raised in which he refers to an objection of mine in connection with the Kinsman system; that is, the obviating the necessity of looking for the signal. I think that is a point in the wrong direction. It is giving the engineman an opportunity for carelessness. In the course of this paper I have given my views on automatic signaling, and I conclude the Kinsman system in practically an automatic system, so that my reasonings in the paper refer to the Kinsman system.

I gather that the Kinsman should be used as an auxiliary to the ordinary signaling. I gather also there must be some sort of interlocking to lock a switch; therefore, you will have all the difficulties of interlocking of the ordinary crossings of points, and in case a train was shunted onto a siding and stood there for an hour or two, every difficulty that is met with in the ordinary signaling will be met with in this case.

I would like to ask a question: About what is the distance at which a train can be brought to a stand?

Mr. Crowell.—That distance is not fixed; that is to say, they can have the contact at any point that may be selected. That can be any distance, speaking reasonably, of wiring.

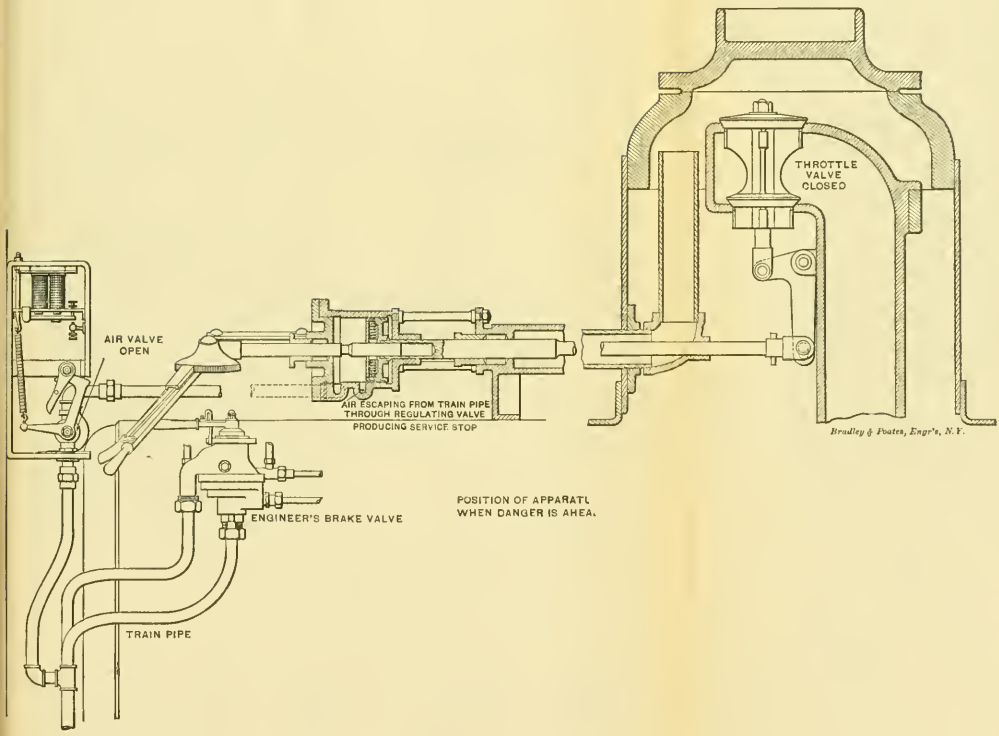
Mr. O'Donnell.—My meaning is somewhat different. Immediately the operation on the throttle valve is performed, to what distance would the train travel before it came to a stand?

Mr. Crowell.—That would depend on the speed of the train.

Mr. O'Donnell.—Take the Empire State Express.

Mr. Crowell.—It can be regulated to apply to an emergency stop, or it can be used for a gradual stop; the ordinary practice would be a gradual stop, for the reason that you always have a vacant block between your protected block and the block in which the danger is; the

PLATE LXVII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 738.
CROWELL ON RAILROAD SIGNALING.



POSITION OF APPARATUS WHEN DANGER IS AHEAD.

Bradley & Foates, Engr's, N.Y.

system is so wired that you cannot emerge from that block without being again stopped.

In regard to interlocking I will say my remark was made in regard to any ordinary switch; not necessarily to an interlocked, but to an unlocked, switch.

Mr. O'Donnell.—We use a similar thing in our system. I asked you the question regarding the distance because Mr. Voorhees, as you remember, stated it would require 1½ miles before the train would stop. That would not suit a majority of the lines in this country.

Mr. Crowell.—The question of speed is entirely independent of the system signal. If you try to stop the train from a visual signal that is too near the danger, it is of no value. In this case there is always a vacant intermediate block, and the blocks can be of chosen length; if the blocks were, say, one mile in length, you would have always two miles in which to stop before coming to the block in which the danger is. Any two trains, if approaching each other, would mutually be stopped.

Mr. O'Donnell.—As I said before, I will not reply in detail until I get Mr. Crowell's notes.

Mr. Crowell (by letter).—Since the Convention I have obtained through Mr. Wilbur C. Fisk, Assoc. Am. Soc. C. E., General Manager of the Kinsman Block System Company, the subjoined table of statistics of operation of the Chicago, Milwaukee and St. Paul installation above referred to, and also a copy of the railroad company's rules governing its use which will be found interesting and instructive.

The illustrations, Plates LXIV to LXVIII, are furnished by Mr. Fisk, together with the following detailed description of the operation in detail for both single and double-track installations.

The operation in detail of the Kinsman system is, for a single-track road, as follows: If a train, which may be represented by *T* (Plate LXIV) is in any section, as *C–D;* the current from the track battery 3, which normally passes through the relay *c*, is short-circuited by the wheels and axles of the train, thus allowing the armature of relay *c* to drop, and so completing the circuit of battery 30, with the exception of the space across from guard rail *x* to opposite main rail; in other words, charging guard rail *x*. The dropping of the armature of relay *c* also breaks the circuit of battery 13, which circuit normally passes through relays c^1, c^2 and c^3. Thus by having the circuit operating these relays broken, their armatures drop, and consequently close the circuits of batteries 23, 22 and 29, with the exception of the spaces from guard rails *p*, *n* and *w* across to the main rails opposite. In other words, a train in Section *C–D* causes guard rails *x*, *w*, *p* and *n* to be charged, and when another locomotive strikes any one of these guard rails, the current is carried to its cab and so causes the throttle valve to be shut and the air brakes to be applied.

In the case of a double-track road, the operation is the same, except that the track is protected in one direction only. For instance, a train in Section *D–E* (Plate LXIV) causes current from battery 4 through relay *d* to be short-circuited. Therefore, the armature of relay *d* drops, causing battery 24 to charge guard rails *r*. It also causes current from battery 13 to be broken, therefore allowing armature of relay d^1 to drop, which in turn causes battery 23 to charge guard rails *q*. Also a train in Section *J–K*, as *s*, will cause guard rails *x* and *w* to be charged.

Copy of Rules peculiar to Chicago, Milwaukee and St. Paul Railway.

CHICAGO, April 8th, 1894.

Engineers,

EVANSTON DIVISION:

The Kinsman block system will be put in service on Chicago and Evanston Division, between Lincoln Avenue and Evanston, north bound, and Evanston and Fullerton Avenue, south bound, at 12 o'clock, noon, April 9th, 1894.

Any obstruction within the respective blocks, such as train, car, open switch or broken rail, will cause steam on engine to be shut off and air brake applied when engine or train enters the first block back of block in which obstruction exists, provided obstruction exists at the time engine or train enters block first named.

When your train is stopped by the shutting off of steam and application of air brake by this block system, you will proceed with train under absolute control until obstruction is reached or until you enter block beyond which obstruction existed.

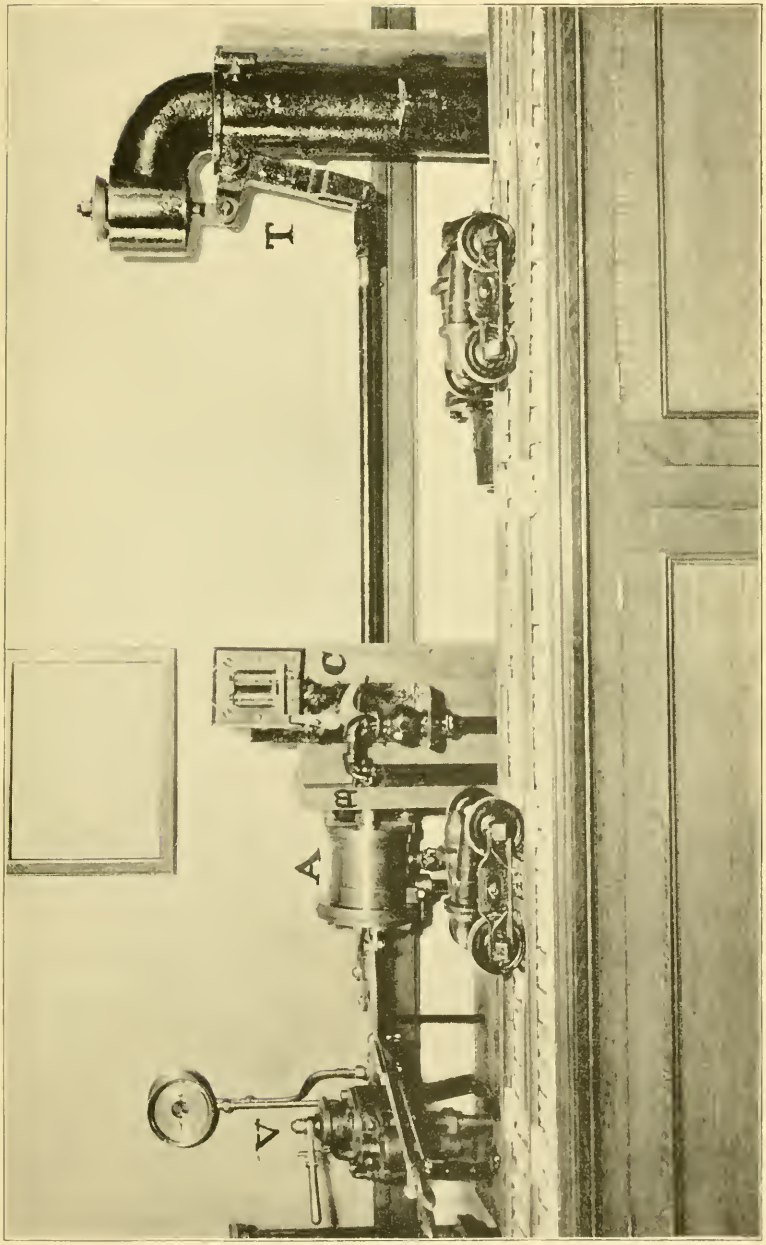
You will make out and send me for each trip, at the end of each day's work, a report, showing application of brakes by this system, on Form 836, which will be supplied at this office.

Engineers will show on this report all cases coming to their knowledge where application of air should have been made under this system, but was not.

(Signed), J. M. BARR,
Superintendent.

Description of plant on the Evanston Division of the Chicago, Milwaukee and St. Paul Railway, and record of its operation from April 9th to August 1st, 1894:

Length of road protected	8.3 miles	
Length of track protected	16.6 "	
Number of blocks	28	
" " switches protected	12	
" " locomotives equipped	7	
" " trains protected	63 952	
" " times "signal" set at danger	127 904	
Application of brakes due to K. B. S		326
Failures in presence of danger		0



Working model showing locomotive equipment in actual relation. *A* is the throttle-stem cylinder, *B* represents the boiler end, *C* is the electric air valve, *V* the ordinary engineer's brake valve, and *T* the throttle.

**Classification of Causes of Stops :*

Trains or cars		145	
Other obstructions		9	
Open switches		4	
Short circuiting (in track circuit) :			
Putting in electric crossing gates	25		
Interference of rods of interlocking plant	10		
Wet slag ballast (chemical action)	16		
	—	51	
Broken line wires		20	
Circuit left open by battery cleaner		14	
Defects in new apparatus		54	
Causes not reported		29	
		—	326

E. E. Russell Tratman, Assoc. M. Am. Soc. C. E. (by letter).—Considerable reference has been made in this discussion to the use of systems for shutting off steam and applying the brakes on a train which passes a signal at the "danger" position, and reference has been made to the difficulty of application of such systems at distant signals (which are admissibly passed while at that position) and at switches. A still greater objection is the necessity of having all engines equipped with the apparatus for closing the throttle without, independently of the engineman. This objection would be specially great where engines of other roads are run and on lines near the shops, since every foreign engine and every engine changed from one division to the other or going to the shops would have to be equipped with this apparatus if the system is to be carried out. Mr. Crowell rather makes light of this objection and refers to the changing of car couplers as an instance of the way in which the engine equipment can be fitted. This does not seem to be a fair comparison, as a car coupler is a single individual piece easily and quickly detached and replaced, while the equipment for the automatic arrangement of an engine includes piping and levers, attachments to the throttle rod, etc., which involve shop work. It would evidently be impracticable to place such an equipment upon an engine operating only temporarily (and perhaps at short notice) on a line fitted with this system of signals. It seems to me that such an automatic (or "train-operated") system may be ranked with the ingenious systems occasionally suggested to enable the engineman to operate the switches from his cab. For exchanging of the train staff a train tablet appeared to be a serious objection to the use of either system of blocking for high-

* A number of stops reported in this table are palpably due to unfamiliarity with the system by the maintenance, force and carelessness or ignorance by section gangs, and, as such, are never likely to recur. It is to be observed that all stops were conducive to safety.

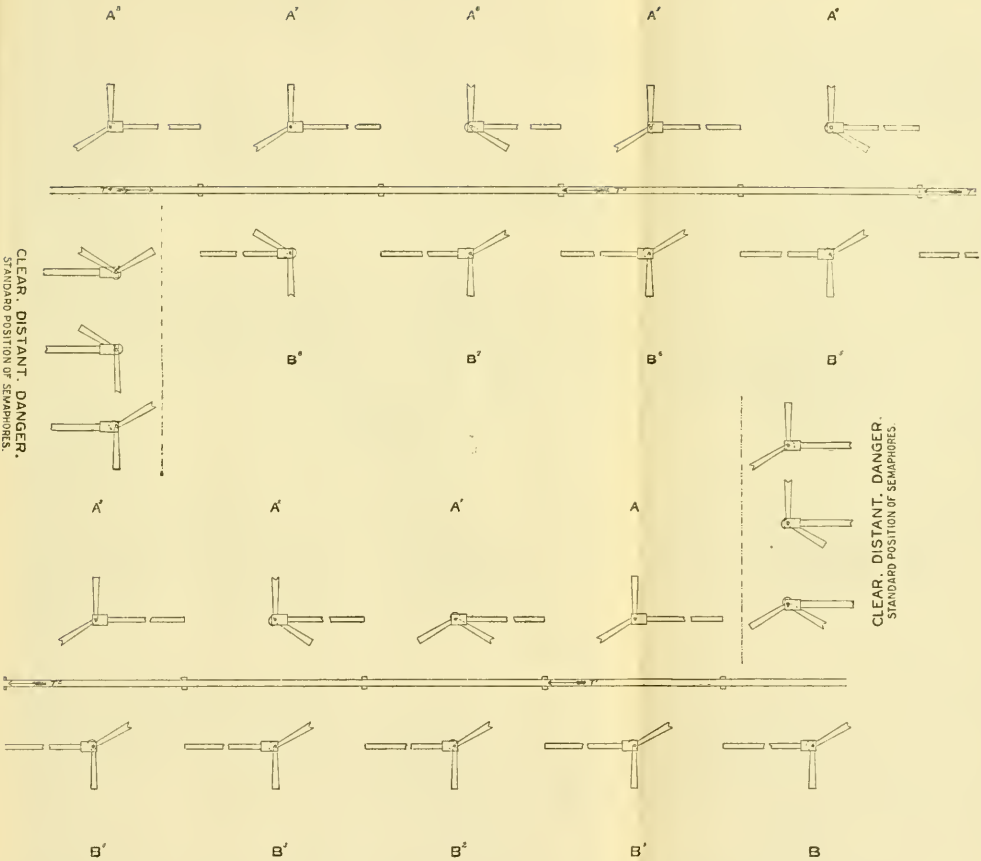
speed trains, but investigation shows that in England, Scotland and New South Wales the Webb, Manson and Quirk exchangers are used at speeds of 15 and 30 miles, and for express train service in the latter country. The latter system has a target or lamp hung to the post when the tablet is in position ; and in the absence of such signal, or if no tablet is taken off by the "catcher," the engineman will, of course, stop his train. Very little reference has been made to actual practice here in the cancellation of signals, as when a train is admitted to a section and is there perhaps sidetracked for a higher class train to pass. The signalman at the far end of the section has given permission for the first train to enter, and is then required to give permission for another before he has seen the first one clear the block. I am strongly in favor of the semaphore arm as the standard form of signal, and of using an automatic arrangement (operated by the train) for putting the signal at danger as soon as a train has entered the block, and locking it in that position until the block is clear, manual operation being then required to lower the signal to indicate "track clear" for another train.

Bentley D. Hasell, M. Am. Soc. C. E. (by letter).—As sickness prevented me from being present when Mr. O'Donnell's paper on Railroad Signaling was read, I beg leave to refer briefly to the article, and the subject on which it treats.

It is to be regretted that Mr. O'Donnell felt compelled to cut short his able and instructive paper on Railroad Signaling, just at the point where block signals must start in the future, viz., Signal Line Working. As about 90% of the railroads in this country are single-track roads, any system hereafter seeking favors must essentially be a single-track signal which will operate equally well on double tracks.

While it is admitted that the systems now in actual use are far from perfect, and fall short of being absolute, and while they seem to cover the field and meet the requirements of the art in a great measure for double lines, they are none of them adapted to single tracks. The reasons for this are many and need not be discussed here, further than to mention the principal objection, which is the cost of installation and maintenance. Any opinion, therefore, on the subject expressed by such an authority as Mr. O'Donnell would naturally start a wide discussion, and result in bringing to the front views of signal experts which would tend to harmonize the many divergent opinions now held and be of great benefit, not only to "contracting companies," but to railroads as well. Consequently, I hope he will find it convenient to write another paper on this particular branch of signal practice at an early day.

The impression conveyed by Mr. O'Donnell, and, in fact, the almost universal opinion, seems to be that an adequate system of block signals for single-track lines has not yet been devised.


A⁸
A⁷
A⁶
A⁵
A⁴
B⁸
B⁷
B⁶
B⁵
A³
A²
A¹
A
B⁴
B³
B²
B¹
B
CLEAR. DISTANT. DANGER.
STANDARD POSITION OF SEMAPHORES.
CLEAR. DISTANT. DANGER.
STANDARD POSITION OF SEMAPHORES.

In this I must dissent, for I have seen a working model (full signal apparatus) of four complete blocks, operated with track circuits, on the normal danger plan, and which system seems to possess all the requisites necessary for the perfect protection against rear or header collisions, as well as against broken rails, trains breaking in two, open switches, or other obstructions, and when the first wheel of the train, in passing, sets the header signal, and the last wheel over sets the rear signal. This system I will now briefly describe, as I have seen it thoroughly tested by running cars, and placing them and the tracks and switches in every conceivable position. The signals have always responded promptly and correctly, following each other into and out of an exposed position.

The principal features claimed are, that it is simple, positive in action, absolute, economical in maintenance and installation, form, for both day and night (color only as an auxiliary), and that the use and dependence upon electricity is reduced to a minimum.

Plate LXIX shows the positions and operation of semaphores in this system of single-track roads.

This system of signals is arranged in series, connected by track circuits, each series serving as rear signals and header signals, according to the direction in which the train is moving. The one series serving as rear signals, when the other is serving as header signals. The several operations are accomplished in about the following manner.

The diagram shows trains T^1, T^2, T^3 following each other on single track and train T^4 approaching from opposite direction. Train T^3 is intermediate of signals A^5 and A^6 (which are the signals for train passing from right to left), and has locked signal A^5 to "danger"; A^6 has gone to "caution" or "distant," thereby locking B^6 and B^7 at "danger," and B^8 locked so that it cannot pass "caution," which position it takes on the approach of train T^4, which train in turn locks signal A^7 at "danger"; so that both trains are at once apprised that the point of danger is at signal post A^7 and B^7. No time is lost in sending out flagmen. Had there been no obstruction intermediate of signals A^8 and A^9, signal A^6 would have shown "clear."

The second operation shows a train T^2 following T^3. When it reaches signal A^4, it is found locked at "caution" by train T^3, the home signal being A^5 for train T^2.

The third operation shows train T^1 just passing signal A, section intermediate of A^1 and A^2 being "clear," signal A^1 shows "all clear." When train T^1 passes A^1, A^2 will show "caution" in same manner as described in second operation. Signals always assume their normal position of "danger" when train passes. The first wheel over sets the header; and the last over, sets the rear. The setting of a signal at "clear" has the same effect as a train on a section. For instance, as long as signal A^1 stands at "clear," A, B^1 and B^2 will re-

main locked at "danger"; and B^3 locked so that it cannot pass "caution." Therefore, it is seen that no auxiliary signals (such as torpedoes, flagmen, etc.) are necessary; and no possible combination of circumstances can bring about a "clear" signal when it ought to be "danger" or "caution."

In this system, there is no strain on the armature of magnets, as electricity is only used for a fraction of a second and then only to trip the power. The arrangement of the semaphore blades (see drawing) is such that the signal can never be misunderstood, as form is the essential feature. Color is not necessary by day, except as a concession to custom. At night, the lights are so arranged, with such colors as are desired, as to show one light for "danger," two for "caution," and three for "all clear," or, if preferred by the railroad company, a fixed light with disappearing spectacles of different colors brought into position by the respective arms for which they are intended.

In this description I have tried to be as brief as possible, and consequently many points of detail have been left out. I think, however, sufficient has been said to convince all that a decided step has been taken in the right direction, and my opinion is, that no signal not fully covering the points outlined in this article will ever hereafter receive serious consideration.

Mr. O'Donnell (by letter).—There is considerable force in the remarks of Mr. B. D. Hasell in his written contribution to this discussion: "That it is to be regretted that the author felt compelled to cut short his paper on Railway Signaling just at the point where block signals must start in the future, namely, single-line working."

On page 451 of my paper I said that any paper on block working is certainly not complete without an exhaustive treatment of single-line working, and, further, that the subject was too extensive and important to be lightly dealt with, and that the matter would have to be left for another occasion.

Undoubtedly, single-line working is of far more consequence, so far as the safety and the results obtained from it are concerned, than double-line working, from the simple fact that head-on collisions are liable on single-line roads, and although possible on double lines, still, they are not probable. Moreover, bearing in mind that 90% of the railroads of the United States are single-track roads, it is undoubtedly the case that signaling for such single lines should have more serious consideration than heretofore, in view of the further opportunities for collisions.

Should no other member of this Society take in hand a paper on block working for single-line railroads, I would be pleased to do so on a future occasion.

The discussion on my paper drifted into an explanation of the merits and advantages of new automatic systems appealing to the public. I regret to say that there was very little discussion on the points raised

in my paper, with the exception of one, which is certainly an important one, and that is, the normal position of the signal.

As to the several definitions of block signaling set forth by the American Railroad Association, that is, the telegraph block, the manual and the automatic, hardly a word was said on these subjects; moreover, the old contentions point of the distant signal even was not discussed, and, as I have said before, the discussion dwindled into an explanation of comparatively new devices for block working. The main portion of the discussion related to the Kinsman block system and to the Hall block system, Mr. Hasell contributing matter relating to his own system. I would point out, however, that my object in writing this paper and any papers, is not for the particular recommendation and particular explanation of any individual system; it is rather to put forward suggestions relating to the fundamental principles of signaling to which any system should conform.

It must be obvious to the railroads of the United States that a general system involving uniform standards is the best for their interests, and it would seem to require little reasoning, or even trouble, to arrive at certain standards which must, in spite of individual exertions, become the standards of the future; take, for instance, the question of the shape of the block signal. Can any one reasonably suggest a disk, which has only color and not position, for indication as against a semaphore arm which has position and color, if you like, though the color is not important for the day signal? The argument in favor of it, no doubt, by those who promote the disk signal, is from the fact that at night the color, which is not considered of importance in the day, is bound to be considered as the night signal, since movement and position of the semaphore arm are not available at night; but, if advantages at day time can be gained by the semaphore arm, there is no reason why an alteration should be made in favor of a disk; moreover, the majority of the railroads of the old world have used the semaphore arm for the last half century, and the trunk lines of the United States, such as the New York Central and Pennsylvania Railroads, have also adopted the semaphore arm.

The question of the shape of the signal is one affecting the engineers of trains. In these days when lines are liable to be traveled over by foreign locomotives it is desirable that a uniform and standard form of signal should be adopted so that an engineer in charge of a train, no matter on what line he may be traveling, will see the same form of outward indication for guidance.

One point that is raised for the use of a disk in lieu of a semaphore as the block signal on a passenger road is the cheapness in the manipulation, but, although this is a point which must be considered by some of the railroads, still, the little extra expense to operate a semaphore arm is not one which ought to be considered in signaling schemes for the safety of railroads.

I am not, as is, perhaps, known, in favor of automatic signaling of any description, and I consider that if the cost were carefully gone into, that is, taking the same results obtained by a manually operated plant and an automatic plant, that the balance would be in favor of the manually operated plant. In a manually operated plant the conflicting switches are generally operated from a central position and interlocked with the conflicting signals, and the expense of this installation is counted as against the operation of signals only with an automatic plant.

In looking over the particulars supplied of the Kinsman block system, it appears to involve three line wires for double track and four line wires for single track; this, in addition to track circuits, would involve a considerable expense, if expense is a consideration. Again, there is a constant current flowing in the track, the battery power being always in use. The Kinsman system, so far as I understand it, has two uses: first, as an automatic block system without the use of visual signals; and, secondly, as an auxiliary to the signals now in use. As regards the abolition of signals, utilizing the Kinsman system as a block system, I do not think it is desirable, for I think an engineer in charge of a train should have some indication to guide him in the slackening of the speed of his train instead of relying at all times upon the presence of a train or obstruction at the box in advance to automatically bring his train to a stand on every occasion where a train should be stopped. If the train should not stop on the treadle bars there would appear to be no indication to tell him when to re-start his train. On the other hand if the train should stop on the bars all he has to inform him is the noise made by the dropping away of the armature in the engine, indicating section clear. The same action relates to a misplaced switch. If a failure occurs on the locomotive, it is fatal to the correct working of the system. Should a failure of the treadle, a fracture of the wire to the treadle, or any damage to the track relay take place, collisions are possible. It would appear that if an obstruction occurs in the section ahead it should return the rear section signal to "danger" if it had been lowered, but this does not appear so from the explanations. In this system, being purely automatic, there is again the point to be considered for the interlocking of signals and switches at stations, and if no signals are used there would have to be some interlocking between the treadles, conflicting switches and locomotive. If block signals are used, then the Kinsman system would appear to be purely an addition for preventing a train running past a signal, to the signaling system now in use on, say, any of the lines in Great Britain, or the New York Central in the United States.

In justice, however, to the inventor of this system, I have to say that I have never seen it in operation, nor even a model of it, and any

objections are only gathered from the pamphlet and description contributed by Mr. Crowell. It is possible, therefore, I may be wrong in some of my conclusions as to detail defects.

Leonard's System.—This system, a description of which I read in the *Engineering News* of July 27th, 1894, appears to be practically as near as possible the Sykes Lock and Block system as used in Great Britain. The tappet attached to the lever and the notch acting as a pawl fulcrumed to the instrument operating in the notch in the said tappet are practically mechanical equivalents for similar parts doing similar duties in the Sykes Lock and Block. The starting signal lever at each section is normally locked until sanction has been given by the section in advance. After the section signal lever, say, the starting signal lever, has been worked over for the passage of a train out of the section, a bell continues to ring at that tower until the lever is replaced to the normal position. This is exactly the same as was fixed at Waterloo, London and South Western Railway, England, in 1892, in connection with all the starting signals—a buzzer, in lieu of a bell, is kept going until the advance starting signal lever is replaced to the "danger" attitude. The signalman, although he need not place his lever back, cannot get sanction from the cabin, in advance, until his lever is replaced. This again is the same as Sykes' (senior) in Great Britain.

Cancellation is allowed and a push-button is provided for that purpose. It is a one-wire system, the same as Sykes'. Short insulated lengths of rail are also provided for track-circuit purposes.

The only difference between this system and the Sykes system as used in this country (which latter is not so good as that used on the New York Central Railroad) is in the details of construction of the instrument. Two double instruments are provided in each box for single lines.

A feature of the invention is, also, by the application of a motor and accelerating gear, that the semaphore is lowered without requiring the presence of a local operator upon the unlocking of its respective lever.

I am unable to offer any opinion as to the details of the method of operation of the system mentioned by Bentley D. Hasell, M. Am. Soc. C. E., in his written communication.

A diagram is attached thereto of a suggested alteration in the outward indication of the semaphore arms to engineers. Two semaphore arms, sometimes both on one side of the post, at other times on the other side of the post, and again at other times one on each side of the post, are set down as indicating by their joint positions certain instructions to the engineer in charge of a train. I have not been able to gather the reasons why such an alteration is suggested nor the objects gained by the same, but it would appear to me to be a distinct departure, and certainly one hardly in the right direction, to mix up

two semaphore blades for one indication, one blade being on the left-hand side of the post and the other on the right-hand side.

There would appear to me to be no reason why a departure should be made from the present system of semaphore blade for home and starting signal, or advance starting signal, and the distant signal blade with forked end; these seem to fulfill, with their present mode of working, all the requirements of railway signaling, and it would appear somewhat late to endeavor to revolutionize this system by a different understanding of these arms.

Again, I may be wrong in my understanding of Mr. Hasell's views.

It is generally fully set forth, and the most made of it, that in the majority of the automatic systems of signaling, whether the several systems promoted and in use in the United States or those tried in Europe, immediately on the operation of a conflicting switch the relative signal is thrown to "danger," or when a switch is misplaced the relative signal cannot be lowered to the "safety" attitude. This may appear to many railway engineers, who have not studied signaling, to be all that is required, for it gives a kind of color to these systems as though the conflicting switches and signals were securely interlocked. Assuming, however, that an express train (for better illustration) is on its journey on a line where an automatic system of signaling is in operation, and that the signal commanding entrance to the next section is lowered to the "safety" attitude, as the train approaches the signal, the switch, which is a hand switch, is either operated by a man on the ground, or, for some reason, springs back or moves out of its correct position, the protecting signal is thrown to the "danger" attitude, but it is not to be expected that the train can stop at an emergency of that kind; should anything be coming out of a siding or shunting in the direction of the main line, the possibility is that it might go through the safety switch and on to the main line that the express is approaching on. This may or may not be a fancied case, but this much remains, that with a manual system, that is, not an automatic system, where the switches and signals are concentrated in one spot and interlocked, so long as the passenger signal is deflected to the "safety" attitude, the lever operating the conflicting switch is locked and no movement can take place out of the siding; that is to say, that the switch is not free to be moved, even although it might put the passenger arm to "danger." The passenger arm is master of the situation, and as long as it is deflected no conflicting switch movement can take place.

Of course, it would be possible to make the deflection of the passenger arm insert a bolt or some other lock into all conflicting switches that foul the line to which the passenger signal applies, but this would mean considerable expense, and, so far as I am aware, does

not form part of the automatic systems generally in use in the United States.

I make these remarks with more particular reference to the statements of Mr. Wallace, as, in view of his experiences with the signals on the Illinois Central, particularly where he says that the closing of the switch automatically would clear the signal, and, in order to prevent the opening of the switch after the train has passed into the block, the switch is provided with indicators and bells, so that after the train has passed into the block the bell begins to ring, and rings until the train has passed out of the block; this would appear to bear out my view that no direct interlocking (by bolt or blade) of the switch by the signal is in operation. It must be obvious that the ringing of a bell, while it may be a reminder, is not a preventive, and that in the rapid passage of trains past a given spot an operator may be excused for not distinguishing between bells, or even hearing them at all. However, no safety is given by this system.

One of the leading advantages claimed for these automatic systems (it should not be claimed as an advantage, for it should undoubtedly be insisted upon as an essential) is that no failures occur in the sense that the signal ever showed "clear" when it should show "danger." It would be an interesting return to see how many times the signals showed "danger" when they ought to show "clear," because in short sections on a busy line where there may be a three or four-minute service of trains, a signal showing "danger," when it ought to show "safety," means blocking the whole of the sections in the rear and thereby suspending the traffic.

I understand that, after a given time where an automatic system of signaling is in operation, the engineer of a train is allowed to pass the signal and proceed cautiously forward; therefore, the instruction to an engineer is exactly the same in a case where a signal has failed to go from "danger" to "clear," when it ought to, as in the case when the block in advance is occupied, and, therefore, the rear sectional signal should be at "danger." The human agency which the automatic system proposes to eliminate would, in cases of this kind, be a valuable acquisition to inform engineers by flag or otherwise, as to the true state of the case, the cause of the delay, blocking of the line, or nature of the accident.

I may say that I regret I cannot follow Mr. Wallace in the distinction which he draws between a disk passenger signal and a semaphore passenger signal. He mentions that at interlocking plants situated at junction points and connections, the tracks are protected by semaphore signals and derails. I gather that it is the derail which is the important question here, and that it is the desire to educate the engineer to take more notice of a semaphore, in view of the fact that if he passes it at "danger" he will be derailed, and that with regard to the disk,

it is permanently employed, so that if he does run by it, there being no derail, he will not go off the line. So far as the traveling public is concerned, it would appear that if two separate forms of the signal are to be employed, that the important one, which is the semaphore, should be employed where there is no derail, and where, if the signal is passed at "danger," an accident would occur. I, however, consider it a very doubtful practice to recommend or even countenance the use of two forms of signals on passenger roads, one of which may be permissive and the other absolute. So far as the meaning of any signal is concerned, except the distant signal, no matter what the shape may be, if in the "danger" attitude, it should command respect from the engineer, and he should be educated to have his train sufficiently under control to stop at it. Therefore, the semaphore arm, which Mr. Wallace illustrates as ensuring more respect from engineers in charge of trains in view of the possibility of a derail beyond it, should be the adopted day signal for engineers in charge of trains, as, after all, the most we want or expect from drivers is to stop at signals and obey them when at "danger."

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IMPROVEMENT OF GRAY'S HARBOR, WASH.

By BOLTON W. DE COURCY, M. Am. Soc. C. E.

READ SEPTEMBER 19TH, 1894.

WITH DISCUSSION.

An examination of the harbors of the United States on the Pacific coast will demonstrate that, in order to make them available for craft drawing over 15 ft., improvements must be made by the general Government. Harbors of refuge are much needed, inasmuch as the prevailing storms in winter cause the shore to be a lee, which circumstance, with the course of the great Japan current, causes loss of vessels and life.

The general Government has had an investigation made, and estimates for a harbor of refuge at Port Orford in Oregon, but nothing further has been done as far as the writer is aware. Appropriations have been made and improvements are being carried out for harbors, or rather, harbor entrances, at Yaquina Bay, the Coquille River entrance, the Siuslaw and Coos Bay, all in Oregon and south of the Columbia River, but no attention has been hitherto paid to any place north of that river.

There are two fair entrances north of the Columbia River, both of which gives the best natural entrance on the coast, north of San Francisco; these are Shoalwater Bay or Willapah Harbor and Gray's Harbor. It is the purpose of this paper to direct attention to the latter alone.

The United States Coast and Geodetic Survey, in the fall of 1891, made a survey of the bar at the entrance to Gray's Harbor, which shows in the line of deepest water a minimum depth of 16 ft.

The crest of the bar at that depth is less than ¼ mile in width, and the distance between the outer and inner 18-ft. curves is about ½ mile; the bar is 3 miles from the gorge of the entrance formed by the two points, Point Brown or Damon's on the north and Chehalis or Peterson's on the south; the distance between these points at low water is about ¾ mile; at high water, 2 miles; at low water the minimum depth at this gorge is 48 ft.; the maximum, 81 ft. These points are the resultants of several natural forces, which are the Japanese current, the prevailing northwestern or southwestern storm winds and the fluvial discharge.

The channel of deepest water over the bar has a tendency to vibrate over a certain distance, but a close examination of the entire crest will show that, although the discharge from the harbor expands and covers a distance of over 3 miles in width, the difference in depth from the line of deepest water is only a few feet less, which assures that, if the water be properly concentrated by jetties, a depth sufficient for any sea-going craft can be obtained.

The Pacific Ocean breaks at the 10-fathom curve, and this curve is closest to the shore opposite to the entrance to Gray's Harbor; therefore, the combers will have less extent, and last January demonstrated the fact that vessels can safely enter at all times, and the depth of water is the only limiting force.

The harbor is somewhat of a heart shape, with the top toward the west. North and south, it is in its greatest width about 12 miles, and east and west about 15; at low water, several channels are developed, with an extent of sand and mud banks separating them.

Besides the Chehalis River, the main stream, there are the Humptulips, the Hoquiam, the Wiskah, the Newskah, the John's and the Elk Rivers, beside numerous creeks discharging into the harbor, the water-shed covering about 3 500 square miles with a rainfall of 90 ins.

There are two well-defined channels extending from the mouth of the Chehalis River to the gorge; these are connected by two cross channels.

The main channels are locally distinguished by the names north, south and middle.

At the east end of the harbor is situated the town of Hoquiam, where are large lumbering interests and immediately adjoining, but on the Chehalis River before it enters the harbor, is the city of Aberdeen, also with a number of large saw and shingle mills, and adjoining this city is the town of Cosmopolis, with the fine lumbering establishment of the Gray's Harbor Commercial Company and several shingle plants.

The annual output of these establishments amounts to, when running at their full capacity, 171 000 000 ft. B. M., and 213 000 000 shingles.*

There are also canneries and other establishments.

The only other town of any consequence on the harbor is Ocosta, situated on South Bay. It has two saw-mills, a tub and pail factory, a brewery, ice plant, flour mill, sash and blind and several shingle factories. It is also one of the termini of the Northern Pacific Railroad, and the nearest one to the ocean being only 3 miles from the entrance between the points.

Several years ago, a survey of the Chehalis River and Gray's Harbor, with a view to its improvement, was ordered by Congress. This was made and a project approved, for laying out an appropriation of $50 000, which sum was expended in the removal of the shoal at Cow Point, between Aberdeen and Hoquiam. Twenty-two ins. in depth was gained over a limited area by this outlay, but at the expense of the lower shoal near the long wharf.

The best authorities hold that improvements to streams should be begun at the lower part, as it is sure then that the benefit is felt of all finished work as you proceed, and this is proved in this case, for the silt and sand from Cow Point shoal was deposited in the expanded channel and added to the shoal caused by the meeting of the waters of the Chehalis and Hoquiam rivers with those of the middle channel.

The work of improvement consists of a system of pile jetties, commencing at the south bank of the Chehalis, and extending by angular

* Report of the Chief of Engineers, U. S. Army.

courses across the south channel, leaving a space of 1 000 ft., mattressed so as to give a depth of 8 ft., with a jetty dam of the same construction across the middle channel.

If the lower shoal had been taken care of at first, the writer believes the results would have been much more satisfactory. He also thinks that where water is to be trained, it is of much benefit to use curves, as water will follow such an alignment, but is sure to cause an eddy where angles are used.

With proper calculations and a curved trace, enough water could have been deflected from the river by a jetty unconnected with the south bank to perform all the scour needed, and this curved trace, with the concave face to the north, would have had a tendency to make the deep channel along the jetty, and not as it does at present, deflect the current toward the embouchure of the Hoquiam River, thus tending to form a bar below it.

These jetties are formed of piling driven 6 ft. apart in two rows, with mattresses of brush sunk and filled in with fascines weighted with stone and sand bags.

The writer is confident that this construction is unnecessarily expensive, as, there being no teredo, a system of piles and sheet piling would answer every purpose, and it would certainly happen that the jetties would fill up with sand in the inside.

From the mouth of the John's River at Markham, north to Ned's Rock, there is a neutral line east of which is a deposit, principally silt. West of this line sand preponderates; this line would seem to be the limit in the main for the silt of the river, and the sand brought in by the flood tide.

Below the mouth of the Wiskah at Aberdeen, the Chehalis River has a width of 1 100 ft. Its mean hydraulic depth is 15.76 ft. at low water. Just below, however, near Cow Point, the river expands to 2 300 ft., with a mean hydraulic depth of 10.18 ft. also at low water. The most natural course for improvement in direction is the south channel. This gives the shortest distance to the ocean, is nearly direct and curved so as to give the nearest channel to the shore, requiring wharfs of moderate length to get to deep water; but the commercial interests of Hoquiam as regarded by those controlling them demand the improvement of the north.

The training of the channel should be done with care. It cannot be

done except at the expense of the tidal area; but if given a proper alignment and direction, as well as a right proportion in width, the volume of water is ample to preserve the requisite depth.

The width should be enlarged as it approaches the neutral line, and in the opinion of the writer should not be carried any further.

The river mouths ought to be trained so as to flow into the main channel parallel to the main stream. The Hoquiam, before the improvement, had such an embouchure, and the two rivers maintained separate channels, the Hoquiam to the north of the lower shoal and the Chehalis to the south of it. The Chehalis, now diverted by the improvement, is filling up. This is proved by the grounding of the United States Coast and Geodetic Survey steamer *McArthur*, and a few days after of the steamer *Point Loma*. Lieutenant Crosby, who is in command, states that the tide was, if anything, over the half when he grounded, and the charts show that there was formerly plenty of water at that state of the tide to float a vessel with greater draft than the *McArthur*.

While the training of the river through the harbor is commercially of the greatest importance, the writer considers the matter of a harbor of refuge of still more consequence. During the last few seasons several large steel vessels, waiting for an opportunity to enter the Columbia River, have been wrecked, with great loss of life, north of the entrance to Gray's Harbor. The last two were the *Abercorn*, laden with railroad iron, and the *Ferndale*, with Scotch coal.

North and south bays give a large area of anchorage and good shelter from all storm winds, and the depth of water at the gorge would give assurance of as deep water on the crest of the bar if proportioned in the same manner. The rise of tide on the bar, according to the notes of the United States Coast and Geodetic Survey, is for the mean of the greater high waters, 9.38 ft., and for mean of the lesser, 7.71 ft. This gives 25.38 ft. and 23.71 ft. as the greater and lesser depths at high water on the bar.

In the harbor this height is increased, as is usual under such circumstances; extreme rise of tide at Aberdeen approaches 13 ft.

It is a difficult matter to procure good stone on the harbor, and the writer is certain that a construction as described for the training of the river, properly modified, would be successful, as the volume of fresh water coming to the bar is so great that frequently quite fresh water

can be dipped up and it is never more than brackish in the main channel, so the destructive teredo is no where to be found, and fascine filling, loaded with sand, would be likely to answer all purposes.

The depth of water at the gorge at low water would also indicate that half-tide jetties would supply all the concentration of force necessary to give a depth sufficient for vessels of the greatest draft, and thus the tidal area would be made available to the fullest extent by the free admission of the flood tide.

The neutral line mentioned, where the sand meets the silt of the river, indicates a deposit of sand brought in by the flood tide, but there is also another cause for this deposit, viz., the prevailing storm winds from the northwest and southwest. This traveling of the sand can be both seen and felt, but can be easily remedied by the cultivation of the *Arundo Arenarea.*

While accretion and abrasion has been going on about the north point, the alterations in the south are scarcely perceptible; in fact, the shore has not materially changed in 11 years.

To conclude, the rules to govern in the main and to be carefully considered are: To give the river a uniform depth by regulating the alignment, flow and width, using formulas found to give satisfactory results by the experience of others, and recognizing the fact that to obtain this the current must be as equable as possible and the channel as straight in direction.

The ebb tide is the most efficient agent to deepen the channel over the bar; therefore, it follows that the admission of the flood must be as unrestricted as possible. Converging jetties, as so successfully used at Dublin and other places, must be used.

Dredging may be advantageous in some places, as thus the silt may be got rid of without a deposit again in some other part of the channel, and, by pumping, the land reclaimed may be sooner rendered available and of considerable value.

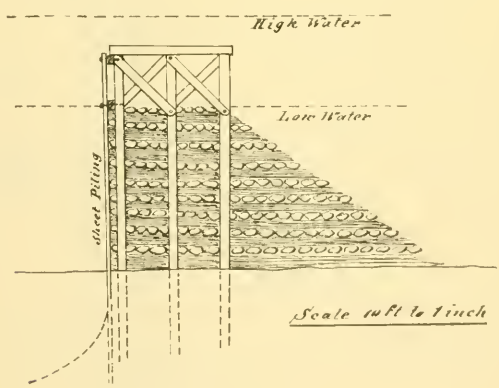
The extreme narrowness of the crest of this bar is occasioned probably by the Japan current causing erosion on the ocean side, and if the jetties be carried to a little beyond, there will be no farther extension of the bar seaward. This current is so pronounced here that vessels entering have to take into consideration a considerable drift to the south.

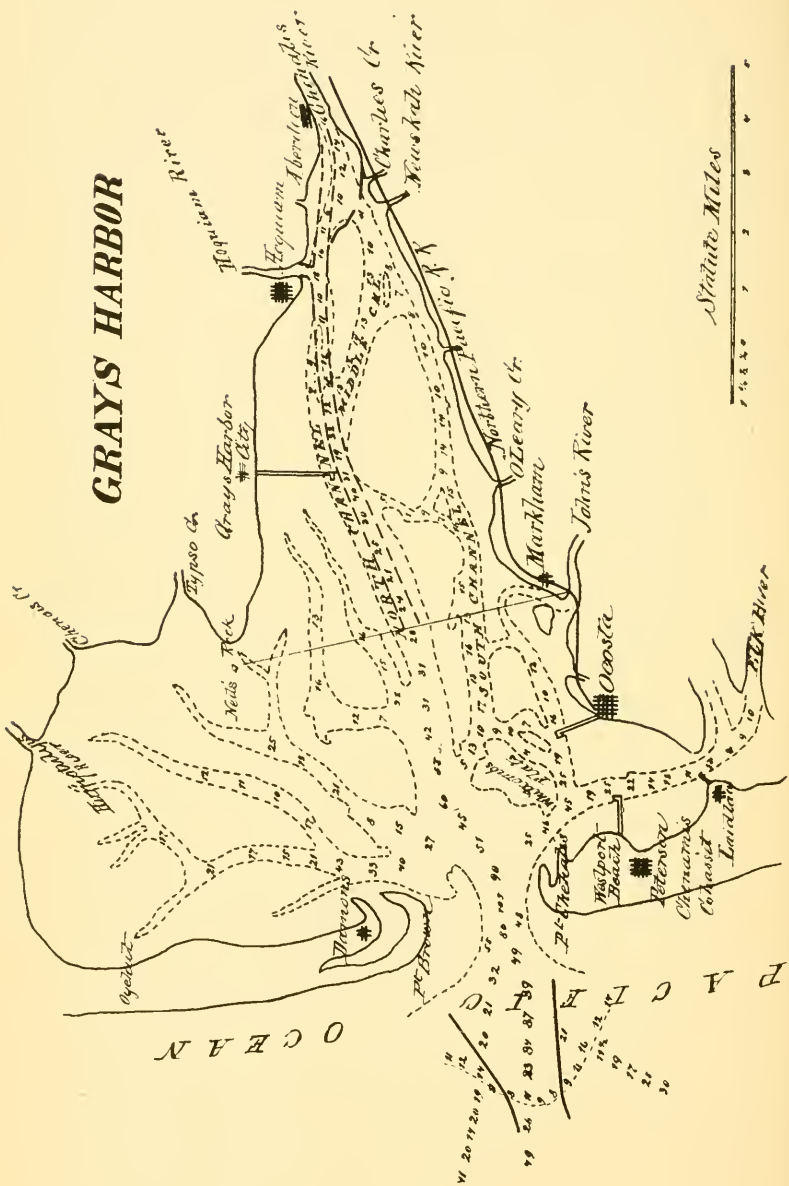
Vessels drawing 17 ft. of water frequently pass out, and the re-

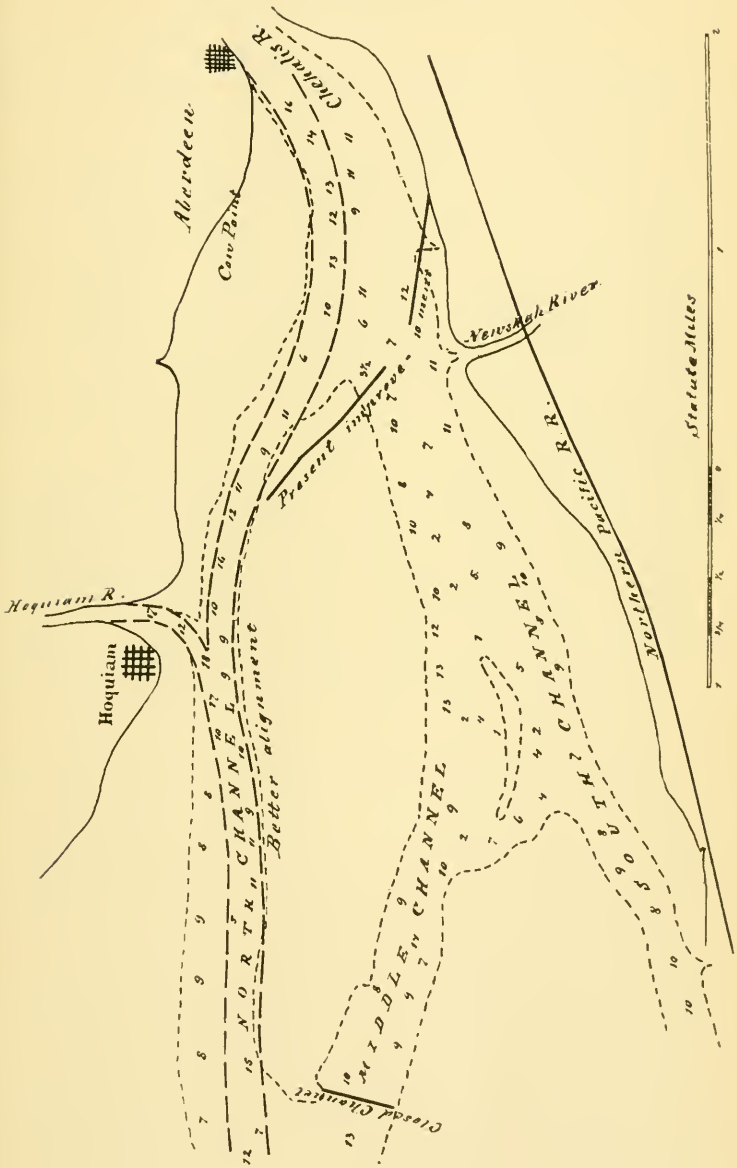
sources of the country in timber and other productions are being developed so fast that, besides the demand as a harbor of refuge, that for improvement for the benefit of commerce is coming on amain and cannot be long neglected.

The ocean greyhounds as used on the Atlantic are scarce introduced on the Pacific, but the tendency is at all times to encourage fast mail delivery, and at this harbor the rail meets the ocean and a whole day can be saved over any other route. The main reward, however, to be obtained is a perfect harbor of refuge, and the saving of fine vessels and valuable lives.

Facts are stubborn things and are incontrovertible in argument; therefore, to prove that this is the best location for a harbor of refuge on this coast, it is only necessary to state the following, viz., last January was a very stormy month, so much so that the two lighthouse tenders *Manzanita* and *Columbine* were bar bound for 23 days in that month at Astoria, inside the mouth of the Columbia River, with a flag of distress flying from the Tillamook lighthouse, and could not get out, and during that time there were only five days that vessels did not pass in or out over the Gray's Harbor bar, and Lieutenant Crosby has told me that he passed in during a severe gale and did not ship one drop of water.




GRAYS HARBOR
Hoquiam River
Hoquiam
Aberdeen
Chehalis River
Charles Cr
Newaukum River
Northern Pacific R.R.
Grays Harbor City
Hyaso Cr
Neds Rock
Cremans Cr
Bishop Cr
Leary Cr
Markham
John's River
Ocosta
Elk River
Westport Beach
Westport
Cranmans Crossing
Landing
Statute Miles
OCEAN
PACIFIC


Aberdeen
Cow Point
Chehalis R.
Hoquiam R.
Hoquiam
Present improvement
Better alignment
NORTH CHANNEL
MIDDLE CHANNEL
SOUTH CHANNEL
Closed Channel
Newskah River
Northern Pacific R.R.
Statute Miles

CORRESPONDENCE.

Thomas W. Symons,* M. Am. Soc. C. E., states that the author's plan for the improvement of the entrance to Gray's Harbor is, as far as the construction goes, probably the boldest and most remarkable that ever emanated from an engineer.

To build two jetties about 3 miles in length right out into the Pacific Ocean, in one of its stormiest portions, on and amid drifting sands, and to construct these jetties of brush and sheet piling driven presumably from a tramway or platform built to a level of mean tide (see cross-section) is certainly a remarkable proposition. Such a proposed construction is entirely inadequate and absolutely impracticable. It would be impossible to build it; but if one could conceive that it could be completed, the first storm would utterly wreck it in an hour.

He is curious to know how the author would build his jetties from his platform submerged at half tide, and which, even in the quietest weather and lowest tide, would be always swept by the waves and swells of the ocean.

In far less-exposed situations, and with a substantial platform or tramway 20 ft. above the water, oftentimes great difficulty is found in constructing and sinking brush mattresses to place. To attempt to control the ocean waves and currents by sheet piling backed by a brush pile is certainly most chimerical. The fact stated in the paper that the waves here often break at a depth of 10 fathoms is sufficient proof to one familiar with the subject that something more substantial than brush and sheet piling must be used to withstand their gigantic power.

As shown on the map accompanying this paper, the depth in the harbor throat is 80, 90 and 105 ft. The author's proposed jetties converge at the bar to a width about equal to the width between low-water lines at the harbor throat. The sands of the bar are easily eroded. The channel between the jetties so confined would be approximately as deep as in the harbor throat. Under these circumstances what would naturally be expected to become of the jetties located as shown, or one of them at least?

The littoral ocean current in front of Gray's Harbor moves to the north and not to the south, as stated by the author. This is proven by the fact that buoys going adrift, wreckage, etc., are almost always carried to the north by the northerly current, which is so well recognized that it is known as the Davidson inshore eddy current, named for Prof. Davidson, the distinguished and able Chief of the United States Coast Survey on the Pacific coast. This current is, however, too slight to have any appreciable effect on the bars or sands along this portion of the coast.

* Capt. Corps of Engrs., U. S. A.

The great southerly Japanese gulf stream, to which the author attributes the narrowness of the Gray's Harbor bar, is felt only at a distance of about 50 miles from shore.

In the inner harbor the construction of the training and controlling dikes is very simple, a double row of piles about 4 ft. apart, filled in with brush fascines weighted with stone, all tied together with wales and cross ties, and all underlaid with a brush mattress.

The author characterizes this construction as unnecessarily expensive and strong. This view is not shared by many practical men on Gray's Harbor, who have expressed surprise that it has stood at all, considering the elemental forces arrayed against it. Some years ago a pile and sheet pile structure, like that advocated by the author, was built in a similar, but less exposed, situation in Tillamook Bay. It was built as substantially as such a structure could be built, but during its first winter it was nearly all carried away. To the mind of the writer it is certain that such would be its fate at Gray's Harbor.

The plan of the work was carefully considered and adapted to existing conditions and demands. The advantages of a curved trace of great radius over a trace of straight lines, connected with slight deviation angles, is more theoretical than practical. The middle channel dike has not yet been entirely completed, and its effect to accomplish the purpose aimed at ascertained.

Notwithstanding the author's adverse criticism of the effects of the works, the writer makes the assertion that as far as completed, they have been eminently successful and give the liveliest satisfaction to the people and interests which they are intended to benefit.

It necessarily takes time for such works to perform their functions and establish a new and better order of things. In the re-adjustment of affairs, it is inevitable that with the deepening of the channel in in some places, there is shoaling in other places, which must account for the grounding of the *McArthur* mentioned.

The author is, in common with many others, impressed with the harbor of refuge idea. In the writer's opinion the question of harbors of refuge along this coast is very little understood; their importance and value is greatly over-rated, and an immense deal of clap-trap talk is indulged in about them. The existence of wrecks along the coast, like the *Abercorn* and *Ferndale*, mentioned in the paper, are pointed out to emphasize and illustrate the necessity of harbors of refuge. The facts are, that these wrecks are almost invariably caused by the vessels getting out of their courses and reckonings in thick weather, mistaking lights or getting disabled and beyond control, and going blindly upon the shore. It is almost, if not quite, impossible to point out an instance of a wreck which has occurred on this Northern Pacific coast in many years which would have been averted by a harbor of

refuge, unless perchance the latter should have been in the direct path which the vessel was blindly or helplessly pursuing.

Under the conditions prevailing along the coast, the best course for a vessel to pursue in the event of a storm or partial disablement is to keep at a safe distance from shore. With the sea running high an attempt to enter a bar harbor such as Gray's Harbor must ever be a dangerous undertaking.

If the entrance to Gray's Harbor is ever improved by the General Government, it must be justified from a commercial standpoint and not from the standpoint of a harbor of refuge.

The opening statement of the paper will cause surprise to those familiar with the natural capacities of the entrance to San Diego Harbor, San Francisco Harbor, and the Columbia River, as will also his statement further on, that the entrance to Willapah and Gray's harbors are the best natural entrances north of San Francisco; better even than the Columbia River entrance. The water-shed of Gray's Harbor is about 2 150 square miles, not 3 500 square miles as stated.

Hon. George H. Emerson writes that he has no doubt that the system of inside improvement suggested in the paper, that of training both sides of the channel, would prove absolutely effective and give a channel of approximately the same width, and approximately the same depth, as at Cosmopolis, or about 30 ft.; the expense, however, attached to such improvement would be very considerable. It seems to him entirely possible that the plan already adopted will accomplish a result adequate to all purposes when complete, if in the coming season the dyke across the middle channel be extended by means of sheet piling 2 000 ft. east from the north end, and 1 000 ft. west from the south end. Tugboats now claim a decided improvement in the channel below Hoquiam, and a marked improvement at Cow Point. They have a tide gauge by which to leave the dock at Hoquiam, and any deviation from their figures, by way of less water, would subject them to detention that would very soon necessitate the correction of their gauge.

Referring to the outer bar he agrees with the author in the statement that, from the crest of the bar to a 10-fathom sounding, the distance is less than at any bar on the coast, and also agrees that the closing of the Chinook channel and the extension of a jetty from Point Damon in a southwesterly direction would probably effectually deepen the crest of the bar. Also, that when once deepened it would be a permanent improvement, and not simply a process of sending the bar seaward, as is so often the case; but he is not of the opinion that sheet piling would stand for such jetty, although he would be inclined to try the experiment, as it might be that sand would form about the piling before heavy storms and the teredo succeed in sweeping them out, but thinks there is no great difficulty in the construction of a jetty

from Point Damon, and that the rock on the Hoquiam River would be of sufficient solidity to resist action of the sea until such time as the sand came to its assistance.

The writer says further, that the survey that is now being made on the bar is with reference to its improvement, and that after having seen the figures resulting from this survey and comparing them with the surveys of previous date, he thinks that, perhaps, much more definite plans may be made as to the course that should be pursued to properly train the waters that pass in and out of the harbor entrance. He agrees with the author that with proper improvement of the entrance of this bay, this will become the most accessible harbor on the coast, and will, perhaps, solve the problem, so long before the United States, of providing a first-class harbor for refuge.

Mr. C. F. White writes that he has carefully read the paper and agrees with the author as to the improvement of this harbor in every particular.

He notes, especially, the reference as to deepening the channel and the system of piles and sheet piling, and endorses the idea in every particular. The absence of teredo in this harbor makes the sheet piling practicable where it would not be if the conditions were the same as to the teredo here as they are in Puget Sound and other places.

Hon. F. G. Deckebach says that he is heartily in sympathy with any plan that leads to the improving of the outer bar; the *modus operandi* he leaves to those skilled by education and experience to deal with such questions.

Concerning the necessity of such improvements as stated in the paper, he says, without hesitancy, that it is imperative, both for the safety of life and property, as well as the demands of the increasing commerce of Gray's Harbor.

The idea of making this harbor a harbor of refuge was first forcibly impressed on his mind by the late Lieutenant Crosby, of the United States Navy.

Before he came to an untimely end in the breakers north of the harbor, he had been engaged in the hydrographic work of the United States Coast Survey between Gray's Harbor and Cape Flattery during five months and had crossed the bar many times and in many directions, and he was very enthusiastic when talking of its improvement, especially for a harbor of refuge; he also considered that one jetty would be sufficient—that to the south.

From this harbor, north, for a distance of over 100 miles, the coast is practically unbroken. No shelter is to be found for any vessel throughout this entire distance.

Nearly all of the vessels wrecked to this north of this harbor were destined for the Columbia River, but from the stormy weather prevail-

ing, they preferred the danger of a lee shore to the almost certain destruction of crossing its bar.

Gray's Harbor bar is considered by ship captains the easiest one to cross on the coast, it being, as they state, only ½ mile across, while that of the Columbia River is about 6 miles.

Congress has made an appropriation for a first-class light to be at once erected on the south point of the entrance.

With an average depth of 16 ft. on this bar there has never been but one instance where an accident occurred in its passage, and this was caused by the carelessness of the captain.

After the entry there is excellent anchoring ground. At the present about 300 vessels pass in and out in 12 months, and with a lighthouse and bar improved, so as to allow the entrance of ships of any size, the danger of wreck will be very much reduced, if not entirely done away with; where they have been frequent to the north of the entrance.

The prevailing current along the coast is from the north to the south. This the writer knows to be a fact, from many proofs, which, during a six years' residence, have demonstrated it.

Common humanity demands that this be made a harbor of refuge, with sailing directions, so that a vessel can enter at all times if it be within the bounds of possibility to do so.

B. W. DeCourcy, M. Am. Soc. C. E., writes in answer to Captain Symons' discussion, that early in the nineteenth century, one of the most eminent engineers in England made a statement that it was quite impossible to build a ship large enough to carry coal sufficient for steaming across the Atlantic Ocean. Afterwards Lord Stanley in the House of Commons declared he would agree to eat up the first steam vessel to make the passage. The truth of the last incident, however, he does not vouch for.

The assertion of the engineer, however, and the commencement of regular steam navigation with the *Sirius*, *Great Western*, *Liverpool*, and other steamships warned engineers to be guarded in their statements, and the word "impossible" has been eliminated from their vocabulary.

The author's suggestion of the sheet piling does not enter into details, but, in referring to the bar while talking of the inner improvement, he uses the words "properly modified."

If the improvement be necessary and it be impossible to obtain rock that will answer, the author does not think the profession of the present day will give up and say that no other plan but the old will suffice. In the inner improvement, he is confident that in the training of the river channel the plan of work suggested could be build sufficiently strong to answer all purposes, and such a plan would cost much less than the plan as built.

The author has had a residence of three years on this harbor, and

has been watching it carefully, and can show single piles that have stood for years and are now standing in the most exposed positions on the harbor, and right where the sea has the greatest fetch, being used for guide piles to the channels.

He is satisfied that if Captain Symons could spend a month or two on the harbor, he would agree with the author in some particulars.

The severest storm occurring here is the southwest; this would aid in the accumulation of sand in the rear of the south jetty, which single work may be as Lt. Crosby considered all that is necessary.

In regard to the ocean currents.

First.—The position of the "line of deepest water" (so called on the original United States Coast and Geodetic Survey chart), the Chinook channel forming an angle to the southwest after it gets outside the harbor entrance, being the resultant of the two forces, the current from the north and the ebb tide and discharge of the rivers both combined.

Second.—The British ship *Ferndale*, loaded with coal, was cast ashore about 10 miles north of the harbor entrance. Her cargo did not scatter to the north, but to the south, and was found all the way along the beach, nearly to North Cove.

A number of others, as well as the author, have seen a dead whale drift away to the south and finally strand near the entrance to Willapah Harbor, the day being perfectly calm, and any wind there was blowing from the south. Boats also getting adrift are invariably found to the south of the harbor mouth.

Third.—The lamented Lieut. Crosby told the author and others that he found the current to come from the north, and that he always had to make allowance for this in entering the harbor.

The author has seen two buoys come ashore that floated in from the north and one of them is to be found at present near the cottage of Col. F. D. Huestis on Chenamis Beach 3 miles south of the point.

The proposition of a harbor of refuge does not emanate from the author, but from those men themselves who "go down to the sea in ships."

The late Lieut. Crosby suggested this place as being the best he had seen along the coast for such a purpose, and, from his standpoint, much needed.

At a meeting at the city of Aberdeen concerning the improvement of the harbor and bar, when the subject of a harbor of refuge was mentioned, Captain Mitchell, an old master, was reported in the papers as follows:

"That he had crossed nearly all of the bars on the Atlantic and Pacific coasts, and with the exception of San Francisco, Gray's Harbor was the safest of all. At Humboldt and Coos bays, where the Government had spent hundreds of thousands of dollars, he had been bar-bound 24 days, while at Gray's Harbor he had never been detained over five

days, and then only when no vessel could have crossed any bar. This bar never shifted much, and he had always found from 18 to 30 ft. of water, and that it was in, his opinion, the best and easiest to improve he ever passed over, and, if improved as a harbor of refuge, would without doubt be the means of saving many valuable lives."

Lastly.—One of the survivors from the *Ferndale* stated that according to their departure, course and reckoning they ought to have had plenty of sea room, but they found themselves in the breakers before they were aware of being near them.

The current not being taken into account, they drifted into the breakers.

Sometimes it is impossible to keep off a lee shore and take that sea room spoken of by Captain Symons ; a lee shore and a storm with a current setting along the shore are hard conditions for a sailing vessel and make a harbor of refuge desirable.

The uncontrovertable proof of the last paragraph of the paper referring to last stormy January shows the capabilities of the harbor. As to the water-shed of the Chehalis River, it is impossible to get a correct or rather exact measurement ; the entire county, except a small amount drained by the North River and a narrow strip on the ocean, is in this water-shed, the area being 2 298 square miles, nearly the entire Lewis County. A part of Mason, a large area in Thurston and part of Pacific, are also components.

The author made a careful examination of the drainage, and is sure he is correct in stating that it has an area of very nearly 3 500 square miles.

With regard to alignment, a famous English engineer says : "All works," referring to training, "ought to be disposed parallel, or according to the direction of the stream, so that the water, instead of being stopped or thrown off, shall glide gently by, with the least interruption possible." * * * "On this account, all angles and sudden turns should be avoided and when a turn must be made, let it have as easy a sweep as possible," etc.

One thing is certain, that the facts are that the ebb tide rushes through the opening left for the south channel with such force that at times it is impossible or dangerous to attempt to row against it, and at this time it draws from some distance toward Hoquiam along the face of the jetty, and at others the deflection of the water from the face can be seen causing a peculiar riffle where it strikes the water of the Hoquiam River at its mouth.

The author's idea was to suggest a general plan, without determining details, for a successful improvement of the harbor.

It will be seen in his discussion that Captain C. F. White, the manager of the largest establishment on the harbor and a practical man, agrees with him.

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PLATEN PRESSES FOR LETTER-PRESS PRINTING, EMBOSSING, CUTTING AND SCORING.

By JOHN THOMSON, M. Am. Soc. C. E.

PROLOGUE.

Letter-press printing, the world over, is known as "The art preservative of arts"; and the compositors, the publishers, the editors and the press-makers may properly be proud of this far-famed legend, for each can safely entertain the belief that he forms an important integral part of the greater whole. Indeed, it is within the truth to say that the "art preservative" is to all modern arts a foster-mother; for it can neither rise nor fall, progress nor recede, without communicating or receiving similar action to or from the arts upon which it is builded. And it is expected that a somewhat similar analogy will be herein shown to exist in engineering.

There has been considerable hesitancy as to the propriety of presenting this paper, relating as it does to a special art and being entirely mechanical. And yet, notwithstanding that it may possibly be looked upon as an innovation upon established usage, there is no little satisfaction in the thought that the craftsmanship which gave life to

engineering is not only itself a preservative of arts but that it is in fact, as in legend, the originator thereof; for Solomon's guest of honor at the opening of his temple, and without whom to-day all arts would decay and crumble, was a master of the hammer, the file and the forge.

But, most seriously, the object the accomplishment of which is desired above all others, as a result of this presentation, is that this quite modest attack upon what has been termed our "unseen barrier" may induce similar action upon the part of others, thereby increasing the scope and usefulness of our Society and making its *Transactions* not only "preservative of arts," past, but as an advance publisher of the engineering progress of America.

Scope of the Paper.

The writer's connection and experience with the "art preservative" has been confined to one of the branches of the mechanical limb, that is, to the design of platen presses employed for general jobbing, fine catalogue and color printing, label and cutwork, book-cover inlaying, embossing, and the cutting and scoring of blanks for the manufacture of folding paper boxes.

It may be proper to state that nearly all of the important devices in the presses to be described are the subject of patent monopoly; but there is no patent, nor is there a protective tariff, upon the experiences which have been acquired, or the mistakes made, in reaching successful results. It is hoped, therefore, that discussion may be freely offered to bring out any feature which may be of interest or value to any one. Only a portion of the drawings, diagrams or illustrations here presented have before been publicly used, and these only in trade catalogues and a few journals entirely devoted to the interests of printers. Moreover, it is not intended to go much, if any, beyond the narration of the personal knowledge of the writer. To do more than this would make a book and involve a history of the art, for which he has neither time nor inclination.

A Few Preliminary Observations.—Principles Involved.

In the United States and Canada there are about 25 000 printing establishments. Assume that the average expenditure of these for machinery each year is but $600, and we have the snug sum of

$15 000 000 as the yearly expenditure for machinery alone, from which it may be inferred that the mechanical department of the printing industry is one of importance.

The duty required of printing presses is most varied and exacting. Probably in no other class of service is the performance demanded of machinery anything like so severe as in letter-press printing and paper embossing, a condition due to the inherent principles of operation, the frequent urgency of output and occasionally to unskilful attention.

Simple contact between types and paper will not print. Printing requires pressure, hard pressure, very hard pressure, and that, too, with extreme accuracy of movement under great strain.

Rigidity of structure is an essential in all printing machinery, but especially is this so in platen presses. In cylinder printing presses the actual surface in contact at any one instant is but a line the length of the cylinder; but in a platen machine the line becomes a plane surface equal in area, say, to 1 000 sq. ins. It is no contradiction in terms to say that a press may be strong and yet not rigid. A hard, unyielding, solid impression is regarded of importance second only to accuracy of operation.

There are some printers who yet believe, as did the earlier members of the craft generally, that long duration or "dwell" of the platen upon the types is advantageous; but this now is not usually accepted as a fact in practice, nor do we find for it a theoretical basis, to which a single illustration will suffice. Thus, in a platen press operating at, say, 1 200 impressions an hour, the actual hard impressional contact over the entire surface of the form will probably not "dwell" to exceed .08 or .10 second. In a cylinder press, however, working at the same speed, the actual contact instant, assuming the breadth of lines equal, say, to .02 in., would not exceed .002 second, or a period of time in the platen press of from 40 to 50 times greater duration than in the cylinder; and yet two such printed sheets might not be distinguishable one from the other. Consequently, it may be accepted as a fact that printing ink is in nowise absorbed by the paper, but is forcibly driven into its fiber.

In a cylinder press, if the face of the form exactly coincides with the pitch line of the rack of the bed; if the face of the sheet to be printed on the cylinder exactly coincides with the pitch line of the cylinder gear; if the tympan is practically inelastic, and if the design

and workmanship of the interacting parts are practically perfect, then the printed sheet may be of the first order. But such an aggregation of conditions are not at all times obtainable, as attested by the fact that types and engravings are more rapidly worn down under cylindrical action than under platen contact. Theoretically perfect rolling contact, as between a type-bed and a cylinder, is demonstrably unattainable; at the same time, the degree of perfection reached by cylinder press makers is remarkable. But this illustration is for the purpose of comparison only, as the field covered by cylinder presses is quite distinct from that of platen machines, and the use of the two are in many cases not interchangeable.

In a platen machine, if the surfaces of both the bed and the platen are practically plane surfaces and parallel to each other; if, with respect to the work to be performed, they are practically rigid; if the movement of one to the other is direct, square and accurate, and if there is adequate impressional power, then the printed sheet may be of the first order; the abrasive action upon the printing surface will be of the slightest possible amount, and the durability of the form will reach its maximum.

To produce a faultlessly printed sheet, at least the following elements must be aggregated: press, ink, paper, form and make-ready; and if each and all of these elements are of the first order, then the result will be the best obtainable in the least time. Should any one of these elements be defective, however, the result will either be reduced quality of product in the same time, or a high grade of product, but in longer time. It is almost, if not precisely, like the ever-occurring problem of power and motion: to obtain one you must give the other.

In fine letter-press printing, the proper delivery of the ink to the face of the form is indispensable to good work. Generally speaking, printers call or refer to this as "distribution of the ink." This means the grinding, rolling or rubbing down of an exceedingly dense, pasty mass into a uniformly thin film, and then, with the utmost delicacy in some cases, to transfer such a film to the faces of the types. So, too, an important element in connection with the distribution is the "ink fountain," employed to feed automatically the ink from a reservoir to the rollers.

In printer's parlance, to prepare a press for printing is to "make ready," and this is ordinarily the duty of that most important func-

tionary known as a "pressman." It is, in itself, a distinct art; a something which cannot be acquired except by actual painstaking trial. The delicacy of touch, the close judgment and the artistic sense displayed by pressmen of the first order entitle them to take high artistic rank. "Making ready" may be likened to the art of straightening rifle barrels or saw plates. Thus, there are those who can strike just the right blow to bring out the kink and no more, who yet may not be able to tell the reason why the desired result was obtained. On the other hand, they who may divinely elaborate the theory of the proper character of blow to be delivered, and may select the proper spot to hit, might add another kink at every clip if the hammer were plied by their hands.

In color printing, where a number of separate impressions are made upon a single sheet, the matter of "register" is of supreme importance. The full meaning of the term "register" as referred to a press, is that the action of the platen shall be so nearly perfect as not to produce a shifting movement upon the sheet. This is not to be confounded with a "slur," which may be otherwise caused, as by a loose or "baggy" tympan, or imperfectly adjusted frisket fingers.

In crank-action presses, the connecting rods and parts attached thereto are restraining members up to the dead center, but become active, driving or transmitting members after the center is passed. That is to say, the parts primarily in tension or compression act like springs to drive the gears, after having passed over the crank-center. Hence, if there is any lost motion, it will be taken up with great rapidity; consequently, back-geared crank presses require close fitting, else there will be a sharp hammer-like shock as the crank pins pass over the nip. In fact, by such shocks, cast-iron gears are frequently broken when the cause is otherwise assigned.

The somewhat remarkable circumstance has repeatedly been observed, that presses used under heavy strain will stand satisfactorily at rapid rates of operation when they will fail if operated at a lower rate of speed; and this, notwithstanding that all the conditions in each case are precisely alike, except, only, as stated, the change of speed. We have no good theory to offer in explanation of this fact, but it is a fact beyond all cavil.

So, also, a form of large area, requiring an exceptionably heavy impression, may not cause the immediate failure of the machine, which is

much more likely to occur under a lighter impression immediately following the heavier; provided, however, that the lighter impression shall be upon a form of materially less area than the first. Probably the good reason for this is to be found in the change of the distribution of strains.

In presses for cutting and scoring paper box blanks, it has been found that if the knives are permitted to take the impression without feeding the sheets, making a direct impingement upon the cutting plate, the sharp edges are much sooner turned than when, as in regular use, they are first driven through the sheet, and thence are arrested by the face of the steel plate. Whether this is simply due to the greater pressure imposed upon the edges, when the obstruction due to the sheet is missing, or that the edges of the knives are cushioned by particles of fiber carried forward under the edges of the knives, is not definitely settled. But as to the definite practical fact there is no question, even although it waits upon a laggard theory.

To emboss a sheet of paper generally requires, it is believed, more pressure upon each unit of surface than would a sheet of metal of corresponding thickness; the reason being that metal, if simply indented, would retain the form, while the fiber of paper, being resilient, must be crushed, deformed, "set," before it will take and retain, sharply, the impress of the die. In some instances, too, no amount of mere pressure will alone suffice; heat must be added to pressure, to co-act therewith, and especially is this so in fibers charged with "sizing," such as are used on book-covers.

An embossing press, running at high speed, strained up to all the fly wheel will carry over, might well be held liable to indictment for inflicting cruelty upon iron and steel; the duty, to say the least of it, is exceedingly severe, much more so than is usually apprehended.

For some years the belief has been entertained that one reason why embossing seems to require, at times, a degree of pressure apparently quite out of proportion to the result obtained, is due to the confinement of air in the cavities of the die; such cells being formed by the paper as it is driven "home," hence, the resilient air acts as a cushion and prevents an absolutely hard contact between the paper and the metal. So far, no adequate remedy has been found for this difficulty. The expedient occasionally employed in drop-forging dies, that is, minute perforations, is not usually applicable in this case.

Development of the Present Machine.

In the briefest outline reference will first be made to the press with which the writer was first connected. This was known to the trade as the "Universal," for over 15 years built by the Colt's Patent Fire Arms Manufacturing Company, of Hartford, Conn. The manufacture of this press was first undertaken, however, by the firm of Messrs. Hamilton and McNeal, at Rochester, N. Y., under patents taken by the (then) Rev. Merritt Gally. The press in several respects was novel but was unskilfully carried out from an engineering standpoint, and, as a consequence, the enterprise resulted in financial disaster, completely wiping out the considerable fortunes of the manufacturers.

The Colt's Company, together with Messrs. E. V. Haughwout & Company and Robert Coddington, Esq., of New York, and subsequently the writer, eventually became interested in the press, corrected a number of its radical imperfections, and turned out a satisfactory machine, of which about 2 500 in all were made and sold. About seven years ago, however, its manufacture was voluntarily abandoned by the Colt's Company, and the writer's present machine, known to the trade as "The Colt's Armory Press," superseded it. And these machines have ever since carried on their side frames, with distinction, it is believed, the company's famous fire-arms trade-mark—the figure of a *Colt*, rampant.

Platen Printing Presses.

The character of platen motion employed in all platen printing presses may be broadly included in two systems—those which rock or roll on a plane and those which vibrate or swing on a fixed axis. The late George P. Gordon, a well-known and successful platen press maker, was the probable originator, broadly, of the rocking platen movement in its application to printing presses. It is shown in an American patent issued to him in 1861.

The advantage peculiar to the rocking platen motion is, firstly, that the lower edge of the platen, *i*, Fig. 1, is carried outward and upward at the same time that the upper edge, *s*, is carried outward, and *vice versa;* whereby a very wide opening is obtained from a short crank radius ; and, secondly, in the ability to change the rocking motion to a direct sliding movement. The consequence of this is, that a direct impact is made upon the face of the form. In all vibrating lever or

link motions, the contact upon the form is angular, therefore tending to crowd the type off their feet, or to spring the platen or the bed, or both. But rolling platen actions, however, have been found exceedingly difficult affairs to manage properly.

Edward S. Renwick, Esq., C. E., M. Am. Soc. M. E., the eminent mechanical expert, in his recently published book, "Patentable Invention," brings out with great force and clearness how the value of an invention, or the importance to be derived from the pointing out of a defect, may be misjudged "after it has been made"; and that an opinion "formed after the event" may be quite a different thing from that

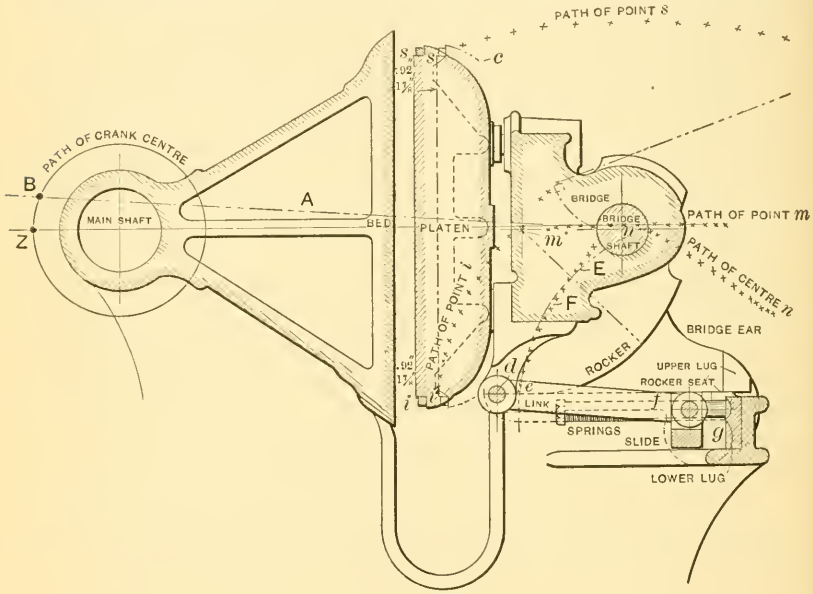


Fig. 1

formulated before it, the thing accomplished, grew to be "obvious." Now, the fundamental defect in the earlier controlling devices undoubtedly came from a misconception of what was taking place in the device *when in motion*, and a fair possibility of its correction would have been opened by this simple criticism: every point in a mass rolling upon a plane surface travels in some form of a cycloidal arc and may be entirely opposed to the action of a device moving in the arc of a circle. But this criticism was not made—fortunately so, the writer is is selfish enough to say—for the omission thereof is probably the cause

of his presence on this occasion. And thus it is that "the realm of an idea may often be defined by geometrical lines."*

In the early design of the "Universal" the platen was controlled by a single helical spring contained within a barrel and vibrating therewith. The assumption was that the rockers of the platen made rolling contact upon the seats; but the fact was that the rockers were not only forced to slip and roll differentially, but the slip, at times, was in a direction opposed to the natural movement. Then as the spring, swinging with the platen, was required to withstand the stress directly, its failure was frequent; and when it failed the entire machine was liable to be smashed, as it frequently was. The spring control shown in Fig. 1 proved as satisfactory in practice as could be expected from any spring device. The arrangement of the springs and slide rods to remain stationary was due to the late C. A. Davis, of the Colt's Company, but the plottings and disposal of the link centers were first made as here shown by the writer; the object being to so situate the swinging center, *d*, that the arc of the circle, *E*, described thereby, should, as nearly as possible, coincide with the cycloidal arc, *F*, which the said center, *d*, would develop if the rockers were free to roll upon the seats. In the direct slide to the impression the springs were compressed, the lugs acting to ensure a parallel movement. A strong objection to this method of control was its noisy operation, due to the practically instantaneous conversion of the rocking movement to the direct or tangential action. In this figure the center line, *A*, represents the main connecting rod, and *B* the center of the crank pin as the platen makes its initial contact upon the form. This indicates the fundamental defect of all simple crank or toggle presses; that is, the applied strain is never at precisely a right angle to the face of the platen until the crank, *B*, reaches the dead-center *Z*. Obviously, the tendency of this is to tilt the platen so that its face shall be normal to the strain. This tendency is restrained by the lugs of the bridge ear which engage upon the rocket seat. It will be apparent that the greater the distance of the lugs from the face of the platen, the more complete will be the control. In this design they were too close, relatively, to the platen, developing a tendency to cramp.

In Fig. 2 is shown an attempt once made to control a rocking motion by means of a link, one end secured to the platen and the other

* Dr. Draper.

to the frame, so that the platen was to slide in a tangent when the upper end of the link was swinging in the arc of a circle. There seemed to be the same abhorrence here between the two geometrical conditions as that alleged to exist between Nature and a vacuum. At any rate it proved impracticable, notwithstanding it was originally said of it that while it might not coincide with fine drawn theories it was "good enough, practically, for printers." It has recently been rearranged, with springs. This device has been shown to point the moral, as the eminent mechanician, Professor Reuleaux, has intimated, that the "bravado" in machine construction knows no limitation, and that there is absolutely no excuse for the modification of a device already well established, free for use and fairly acceptable, unless the change carries with it a definite improvement; whereas, if the change is retrograde it becomes an engineering crime, in that all are thereby caused to suffer.

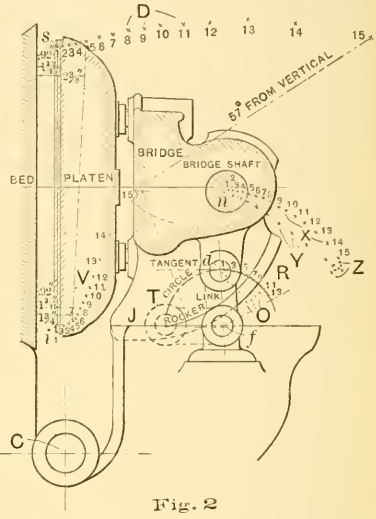


Fig. 2

At *C*, Fig. 2, there is indicated the vibrating principle of platen movement, in respect of which no time will be consumed, except to assert that it is obviously fundamentally imperfect, in that the impressional contact is angular, or as if imparted by a pair of scissors. It is sometimes facetiously referred to in the trade as the "clam shell" movement. This principle, however, has been widely adopted in a great variety of modifications; and here an important lesson may be learned, namely, that a theoretically defective device may long continue in use, and that, too, with fairly satisfactory results, provided, as is the fact in the instance at hand, that the relative degree of the error is small.

Fig. 3 is a reproduction of the drawing appearing in a patent for a mechanical movement granted to the writer in 1885, which had for its object to show in the broadest manner a new method of controlling the action of a curved body 3, rolling upon a plane 2, or the arc of a

curve rolling upon another arc. This is obtained by cams 9, 10, attached to the curved body and moving therewith, while the cam rollers 6, 7 are mounted upon the side 1 of the plane.

As this movement appeared to be entirely novel, no references of any kind ever having been found against it, and has had considerable commendation, at least from geometers, it is thought that the following quotation from the patent specification, originally drawn by the writer, may be of interest:

"It will now be apparent that if the arc be rolled back or forth upon the plane the character of the action, that is, whether rolling on the plane or a combination of rolling and sliding, will be governed entirely by the shape of the cams; but as the end here sought is to maintain a

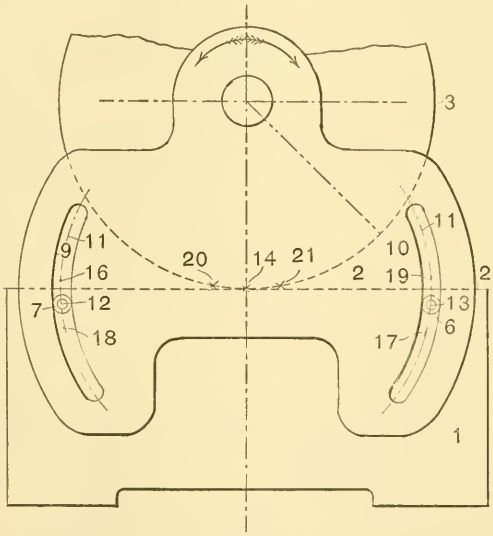


Fig. 3

perfect rolling action, the mathematical condition necessary to effect this is, that only one point in the curvilinear planes 11 of the cams shall coincide with but a single point on the surfaces of the arc and the plane on which the arc rolls, that is, by demonstration, the points in the planes at 12, 13, bisecting, if it may be so expressed, the center of the rolls can only be at that position when the point 14 of the arc is in the vertical line of the plane. With the points 16, 17, or 18, 19, bisecting the centers of the rolls, we should then find the points 20, 21 of the arc in the vertical line, and so on. As there is but one system or class of curves known which meets this condition, the statement of the problem in effect answers it, namely, that the required

form of the cam or cams shall be that of a cycloidal curve, in the projection of which the arc is the generating circle, the plane surface is tangent of the generating circle, and the fixed roller the describing point. I have just referred to the required form of curve as a 'system or class.' This is correct, in that the curve of the cams would only be a cycloid in its strictest interpretation when the center of the friction rollers exactly coincided with the plane on which the arc rolls; but as the principle involved in the projection of the curve is the same in any instance, whether the describing point be on the circumference of the generating circle or within or without the said circumference, or be the point in the plane on which the generating circle rolls, or above or below it, or whether the plane were also a curved surface (in which instance the curve would be an epicycloid), the result produced would be one and the same in every instance. The plane may be rolled upon the curve, in which case the friction rollers would traverse the cams. The term 'plane' as herein employed is used in its broadest sense, without limitation as to rectilinear or curvilinear projection."

In Fig. 4 is shown the practical application to a platen A, having

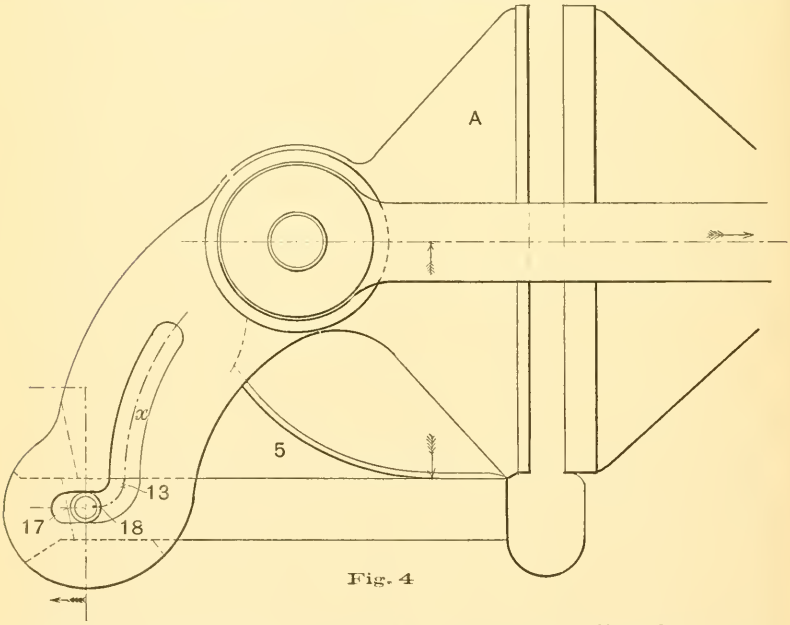


Fig. 4

rockers 5, of the principle illustrated in the preceding figure, but with two important additions. First, the arbitrarily curved section between 13 and 18, joining the cycloid x on the one side, and also,

second, joining the tangent 17, 18 on the other. In this wise, the rocking movement conforming to the cycloid is gradually merged by the curved section, without the slightest shock or jar, into the tangential portion, thus permitting the platen to slide with perfect freedom and parallelism to and from the form.

"In this manner," to quote again from specification records, "the movement of a mass which may weigh hundreds of pounds is produced with practically no friction during the chief—the rolling—portion of the motion, while the said rolling motion is converted into a reciprocating sliding motion without noise, shock or material wear of the parts. The rocking block is also positively locked against displacement in every position which it may occupy, so that it cannot slide during the time when it should rock, or rock during the time when it should slide."

In Fig. 5 is shown the first application of the new controlling device, the cam being made as a separate part attached to planed seats on the platen bridge and on the center thereof. As shown, the walls of the cam are cut away, top and bottom, at the right hand of the tangent of the curve, corresponding to the direct slide just prior to the impression, so that the cam and its roller are never subjected to severe strain, but simply act to ensure the proper rolling motion of the bridge and platen. The duty required of the cam is very slight, in that the thrust upon the roller is constant, changing only when the motion of the platen is reversed, thus ensuring the durability both of the cam and of the roller.

The aforesaid figure also shows what was termed the dwell-cam 28, attached to the crank pin. The eyes of the connecting rods were slotted so that the crank pins could traverse back therein. In this wise the platen would be driven by the crank pins from the vertical position to an angle of 45°, as at 40, whence the dwell-cams would assume control, carrying the platen still further out, as to 46, an angle of 68°, and at this position the platen would rest or "dwell," the crank pins meantime moving within the slots of the rods. The presumed advantage of this dwell-cam arrangement was that it realized a distinct gain in time and a more favorable condition for feeding the sheets.

In Fig. 6 is shown the dwell-cam as applied to the "Universal" press by the Colt's Company. This device was originally suggested by Mr. L. C. McNeal, one of the originators of the machine, but the

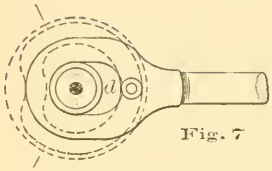


Fig. 7

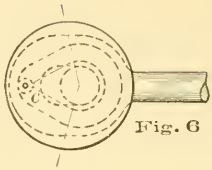


Fig. 6

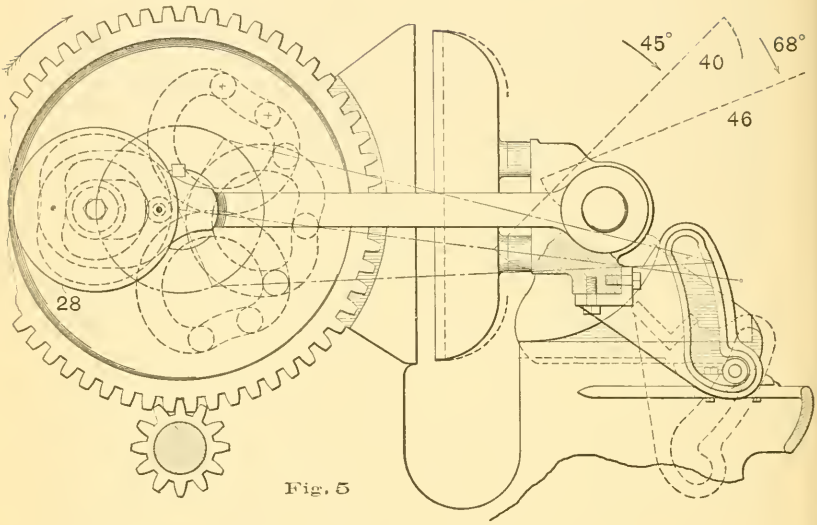


Fig. 5

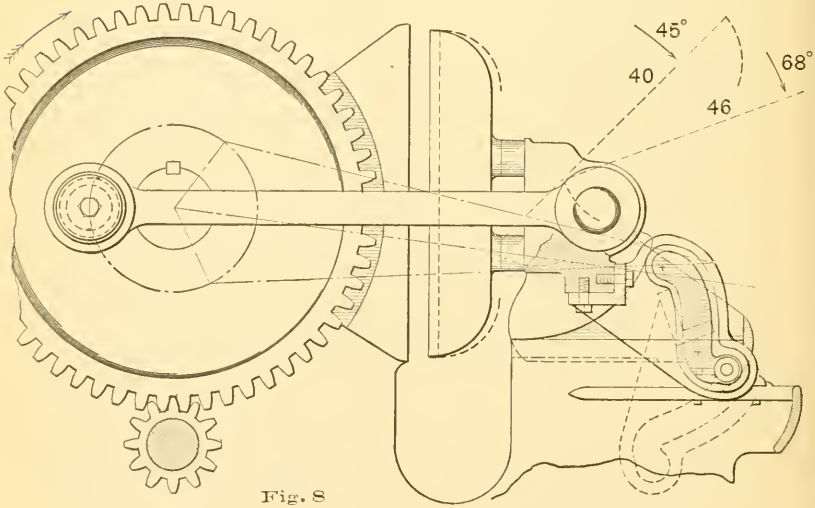


Fig. 8

form here shown was jointly due to Mr. Davis, already referred to, and to Mr. Charles B. Richards, once a Member of this Society, who at that time was the Mechanical Engineer of the Colt's Company. While the operation of this was all that could be desired when new, the original fault remained, that the roller pin *c*, being inserted in the front of the connecting rod "eye," weakened the same, and that the unsupported crank pin was unusually liable to cut and grind. This was obviated by the writer in the design shown in Figs. 5 and 7, the location of the pin being changed to the opposite side of the crank pin and a free sleeve, *d*, being applied over the crank pin. Thus the sleeve would act as a friction roll when traversing the slot, but would lock in the end of the slot and act as a bushing for the crank pin during the impression.

Up to about this time the idea was more or less dogmatically fixed in the mind of the writer that the form of the platen-controlling cam must be such as to cause rolling contact between the rockers and their seats. And thus does the rut of habit "make slaves of us all." Finally, through a thick and hardened crust, came the thought, Why not cause the rockers to slip with a constantly differential movement? It was tried between two mornings experimentally, and the final result is shown in Fig. 8. In this, by simply curving the upper portion of the controlling cam forward, the slotted connecting rods and the dwell-cams were thrown aside, and by thus causing the rockers to roll differentially and slip through a portion of their swing, the platen was carried outward, in the same time as before, to the 45° angle, while its further progress to the 68° angle was also accomplished in precisely the same time as before, but with the single difference that it was swung through this 23° space at a slower rate of speed. Not only did this simplify the machine and materially reduce the cost of its manufacture, but it increased the safe practicable feeding speed by easily 25% while the limit of its durability is not known; as up to the present time, covering an experience with over 1 000 machines, there has not been, so far as heard of, a single failure.

Fig. 9 (Plate LXX) is a half-tone illustration of a complete printing press, from the fly-wheel side. Attention is directed to the combined belt shifter and brake, by means of which a single thrust of the hand shifts the belt to the loose pulley and at the same time applies great friction to the fly wheel. The hand lever, at its lower end, extends

inwardly, like a bell crank, and at its extremity the brake shoe is attached through the intervention of a ball and socket joint. This ensures, under all circumstances, a proper contact upon the face of the fly wheel. But the brake power is especially effective because of the location of the shoe, as it will be seen that its contact upon the fly wheel is not direct, as it would be if below the center of the shaft, but makes an oblique impingement, analogous to the action of a wedge. With this appliance a boy can stop the press within the period of a portion of one revolution, when the fly wheel, weighing 150 lbs., is revolving at the rate of three revolutions a second. In this device the only mistake made, commercially considered, was that the writer did not have the forethought to apply it earlier; for when your printer-editor will look with a cold and irresponsive stare upon cams, cranks and rockers, there will come over his countenance at least a shade of warmth as he operates what he is pleased to term the "switcher." And there may be the best of reasons for this; for he may have stood in front of a swiftly moving platen, at some time, with the carriage bumping over a loose form, and no means for quickly averting disaster.

The chase (the iron frame used for locking up the form) is secured to the face of the bed by a latch, operated by the short pedal shown in the right-hand side of the engraving. Thus the chase may be quickly tilted forward or removed by the pressman, who, having both hands free, elevates or permits the depression of the latch entirely by the pedal. The pivoted guard above the pedal is to prevent accidental depression. This is swung upward by the foot when desirable to operate the latch, but it swings back automatically upon withdrawing the foot. In other words, the pressman or feeder, to operate the device, must first think.

The main connecting rods are of steel, finished by drop forging, and are produced from a solid billet of metal, without welding. This method, and the detail in connection therewith, was carried into successful practice by Mr. L. C. Grover, M. Am. Soc. M. E., Superintendent of the Colt's Arms Company. The grade of steel used is such that the average tensile strength is about 70 000 lbs. per square inch of section, with an elongation of about 20 per cent. in test specimens.

The impression may be thrown off at any part of the platen motion, by disconnecting the latch of the adjuster bar, shown at the right-hand side of the platen, and then swinging it downward with its attached

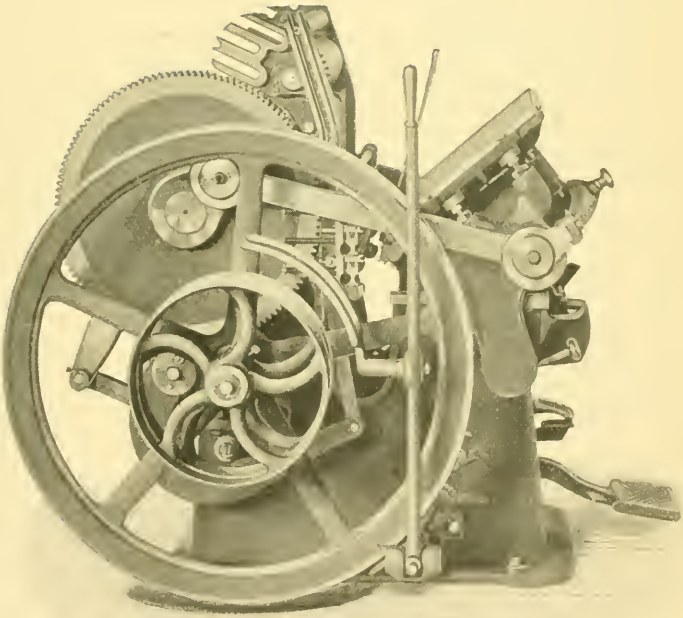


FIG. 9.—Half Medium, Style 1, Platen Printing Press.

eccentric sleeves. The effect of this is to lengthen the main connecting rods.

The plan here employed for oiling the crank pins is believed to be novel, consisting in drilling a hole lengthwise through the washer bolt to reach the cavity at the end thereof. This forms an oil reservoir. Then a hole, *A*, is drilled transversely through the crank pin, to intersect the said cavity. Consequently, at every revolution of the crank pin, the oil runs out and back again, constantly washing the bearing surface with the lubricant. Since this arrangement cut crank pins have been a rarity.

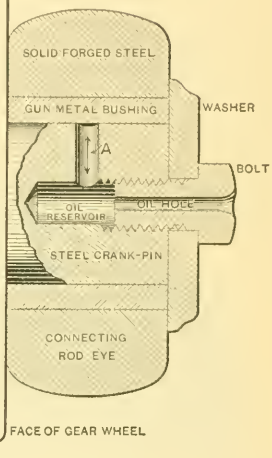


Fig. 9a.

In Figs. 10, 11 and 12 are shown the details of the ink cylinder, for distributing the ink, which result is obtained by causing the cylinder both to rotate and to reciprocate. The smaller bevel gear is fixed to the carriage-way and does not rotate. The larger bevel gear is mounted upon an arm fixed to and moving with the cylinder shaft. Hence, the larger gear has a compound movement, rotating with the cylinder and also revolving upon its own axis. The latter is termed the traveling gear. An eccentric stud upon this traveling gear carries a steel slide block engaging a slot in the cylinder. The consequence of this is, that the cylinder as it rotates is also driven back and forth, the extent of this movement being equal to the "throw" of the eccentric stud. The velocity ratio of the gears is such as to produce a relatively slow "vibration," and at a speed differential to that of the rotation. Therefore, the reversing action has little or no tendency to tear the composition rollers, although the distribution, that is, the grinding of the ink to a thin, uniform film (which simple rolling will not accomplish), is of the highest order. A point of special advantage in this action is that both the form rollers and the distributor rollers are acted upon at the same time; also that, being contained within the cylinder, no extra space need be provided. The initial driving action is derived from the spur gear, which meshes with the main crank gear, and turns the cylinder by the two driving pins, which are freely fitted

to their bearings in the cylinder, thus permitting it to be slid back and forth. Two errors of judgment were made in the first design of this device. First, in driving the cylinder by a spline in the cylinder shaft, this not having sufficient bearing surface. The two pins, driving right and left, balanced, were a complete remedy. The second error was in not confining the revolving spur gear endwise to its journal. By this omission the thrust of the gear was borne by the faces of the slot in the cylinder; hence, when the work was unusually heavy, these gears were liable to fail. This difficulty was entirely obviated, however, by confining the revolving gear to its shaft, making it a self-contained structure, by means of an end plate not shown in the engraving.

Fig. 10

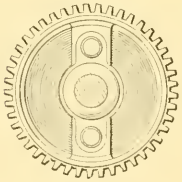


Fig. 11

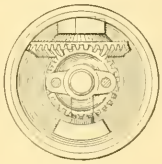


Fig. 12

DETAIL SECTIONAL VIEWS OF INK DISTRIBUTING ACTION.

The half-tone, Fig. 13 (Plate LXXI), is to show the detail of the ink fountain, also the apparatus for actuating the carriage which carries the form-inking rollers. The operating parts of the fountain are best shown in the detail view, Fig. 14, but will not be closely described in all of their detail. The spiral spring, acting upon the arm of the vibrator frame, swings the ductor roller from the fountain cylinder over to the main ink cylinder. A spring is here employed by preference, as it secures an elastic contact upon the main ink cylinder and allows for the considerable changes in the sizes and form of the composition rollers, which not infrequently shrink nearly 10% of their diameters. These

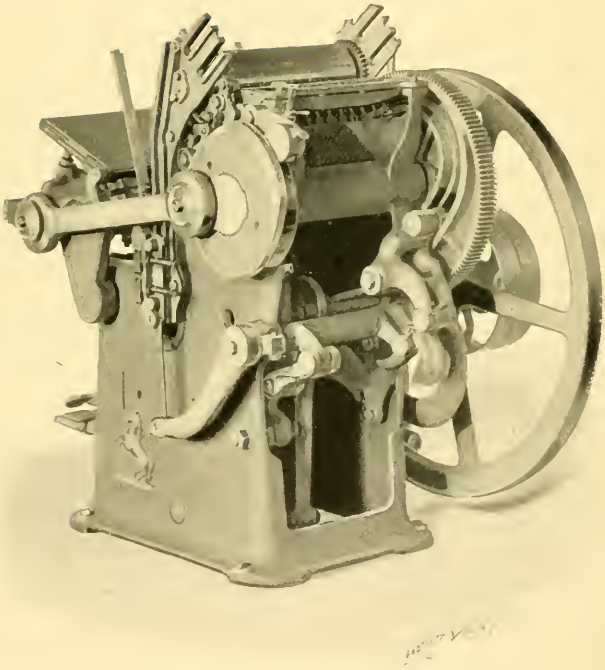
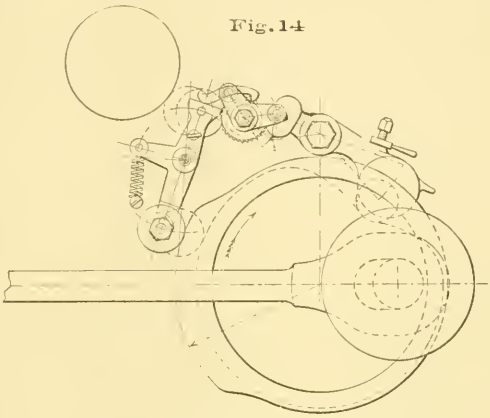


FIG. 13.—Quarto Medium, Style 1, Platen Printing Press.

movements are accurately timed, relatively, so that the contact of the ductor roller upon the main ink cylinder takes place as the carriage starts on its down motion; thus the supply of fresh ink from the ductor roller is distributed during the time that the form is being inked; while, conversely, the ductor is at the fountain while the form

Fig. 14

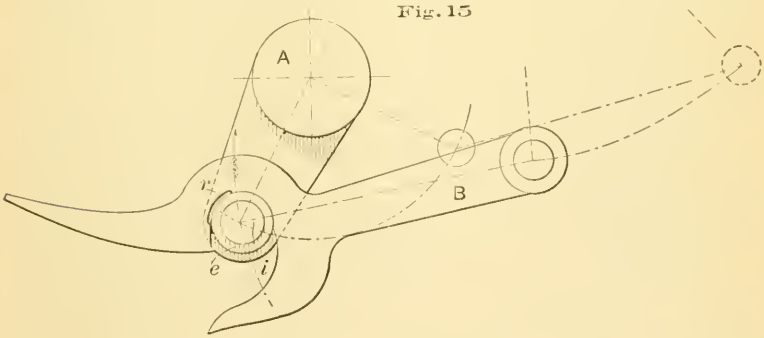


DETAIL VIEW OF APPARATUS FOR OPERATING THE INK FOUNTAIN.

rollers are upon the cylinder. The feed may be instantly stopped or started, without stopping the press, by simply swinging the ratchet pawl in or out of engagement. So, too, the number of ratchet teeth to be engaged may be quickly changed by adjusting the thumb-screw in the main driving lever.

Fig. 15 shows a detail of the carriage action. In these presses the

Fig. 15



DETAIL VIEW AND DIAGRAM OF THE HOOK-CONNECTION.

carriage may be stopped upon the cylinder by simply drawing the projecting handle, which is shown on the left-hand side, front, of the frame,

Fig. 9. The advantage of this is, that the ink may be thoroughly distributed upon the rollers while the form is in the bed, the press being operated without smearing the form. The device is positive and may be operated at any time, either to engage or disengage. In this connection, the chief feature to be pointed out is shown in Fig. 15, and consists in the application of the steel friction roller *e* to the hook pin and recessing the quadrant *r* of the hook. In the earlier movements of this character the hook made direct engagement upon the pin *i*, the consequence being that both the pin and the hook wore very rapidly and developed excessive lost motion. Besides, the circular sweep of the rocker shaft *A* had a provoking tendency to lift the hook out of engagement with the pin. By the present arrangement the hook is forced to stay in proper engagement and the wear is almost entirely confined to the pin.

The writer may say that the definite location of the fault in this device, the discovery of why the hook might properly maintain its engagement for 99 operations, and then in the case of the 100th would apparently lift itself out of gear, and, like a balky horse, without reason, simply quit, was one of the most perplexing problems he ever had to deal with. Presses were closely watched in operation, for hours at a time, the automatic disconnection going on at irregular intervals, until finally one of the watchers threw up his hands, saying: "Well, I give up; it must either be a devil or a hoodoo." But it was neither; and here is a word for theoretical demonstration. The writer firmly believes that the movement might have been watched for a year without discovering the cause; for, upon a more careful plotting, in a drawing of large scale, he discovered not only that the swing of the rocker-arm shaft was making a perfectly legitimate effort to roll the hook out of its engagement, as indicated in the drawing by the arrow, but that this was augmented by the fact that the thrust contacts as between the two arcs were favorable to the fault; that there were two tendencies at work at times to produce the fault. Theory having pointed out the cause, the practical remedy was almost obvious; at any rate, the desired result was obtained by a few strokes of a half-round file; consisting, as shown, in removing the quadrant *r*, which was the field of the interfering action.

The movement of the carriage back and forth over the form has been the subject of the greatest care and attention, whereby to effect a

perfectly cumulative start, reverse and stop, with such a disposal of the motive mechanism as to ensure durability at high speed of operation. This action is derived from the cam formed in the inside of the main gear, best shown in Fig. 13. The detail of this cam and its development will not be described, as it involves only the work which any competent engineer ought to be able to carry out. There is one feature here, however, which may be adverted to, corresponding somewhat to the transition curve theory of railroads, namely, that all cams should have their starting point materially farther back and their entering curve of materially greater radius than might appear called for theoretically. The reason for this is, that the point marked for the theoretical divergence from the concentric arc or the tangent is seldom if ever the position at which the actual initial divergence takes place; for the reason that, although the mathematics of the plan on paper may be perfect, in actual mechanism the lost motion and spring of parts are often sufficient to neutralize the easement. Hence, when the deflection does take place, it is at too rapid a rate of speed, and the result is a shock or undue wear of parts. Ergo, if there were no lost motion and greater rigidity in railroad cars, would not many of the present curves have ample easement?

Fig. 16 is a diagram which may be of interest even to those somewhat familiar with printing, and it is to show the reason why a hard "tympan" (that is, the sheets used on the platen to cushion the impression and on which to make ready) will, other things equal, be easier on the type and produce a better effect than when a soft, yielding tympan, a pillow, is employed. Obviously, when a type is forced into a yielding tympan, as shown, it not only indents the paper, but quickly rounds off the sharp edges of the type; whereas, the sharp, square type coming into accurate contact with the hard, inelastic tympan, will represent contact under pressure, but without abrasive action. So, too, the type marked "underlay" indicates the best method, when permissi-

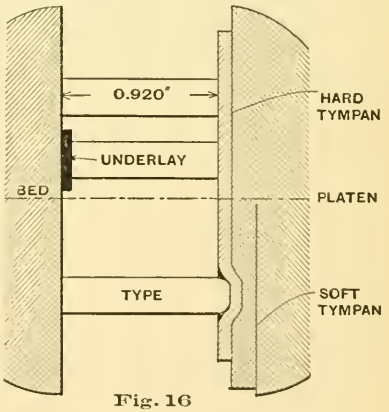
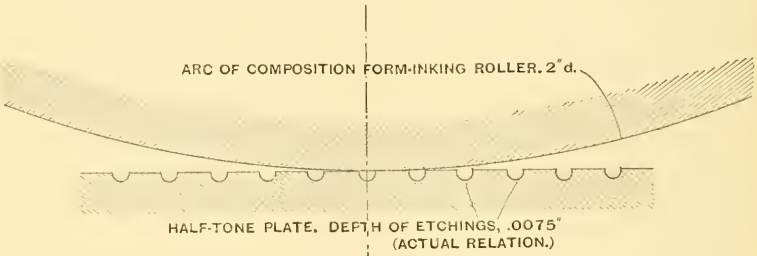


Fig. 16

ble, of correcting a defective impression, which is to bring the low types up by packing from below, rather than by "overlaying" on the tympan. The printing of daily newspapers is not included in the foregoing. In such work "blankets" are used upon the impression cylinder, and punching would be a more appropriate term than printing.

The diagram, Fig. 17, is intended to represent the delicacy of contact and perfection of movement necessary to ink properly the now widely used "half-tone" engravings. Thus, not infrequently the



PRINTING.

Fig. 17

height of the points bear a relation to the form roller of as 1 : 1 000, and it will be apparent that the slightest fault in the distribution of the ink or "drag" of the rollers as they pass over the engraving would result in filling the recesses, causing a smudging of the sheet.

Fig. 18 (Plate LXXII) represents a special press adapted to a combination of purposes. This machine is provided with double steel-section gears and double fly wheels. The shafting, crank pins and connecting rods are as heavy as can be swung in the space available. Comparatively few of such machines have heretofore been made, the demand necessarily being limited; but in several instances a single machine has been adapted to produce the following range of work: embossing, book-cover stamping, with either hot or cold dies; book-cover inlaying, wood printing, up to 1 in. in thickness; cutting and scoring of paper blanks and any variety of color or letter-press printing.

Embossing Presses.

Next in order of importance come presses adapted for embossing. The lighter grades of work may occasionally be executed upon platen printing presses, but even when constructed in the strongest and most

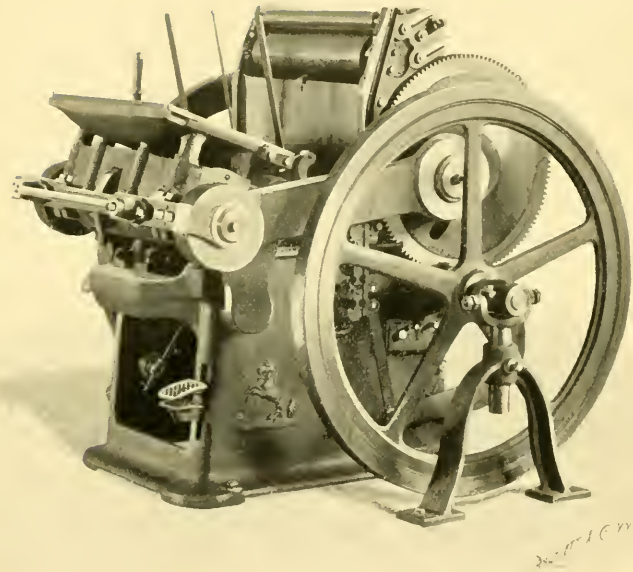
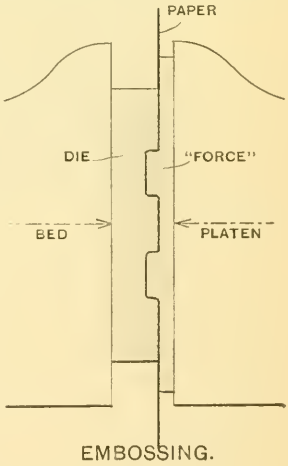


FIG. 18.—Combination Platen Printing Press.

rigid manner the usual effect of embossing is to lower more or less the efficiency of the machine as a printing press, the reason for which is, that the hard pounding, the hammer-like shocks, often experienced in embossing result in hollow beds and platens. Moreover, frequently the heaviest impressions are imposed upon dies of small area, thus centralizing the strains upon a small surface. In embossing practice, a heavy die is not necessarily of large dimensions, as its "heaviness" is much more dependent upon the number and character of the lines or points to be brought up in the paper than in the mere upsetting of blank surfaces having greater area.

Another condition of unusual severity to be contended with in embossing is, that dies may frequently be set out of proper center. Sometimes this cannot be avoided, but most frequently it is caused by error of judgment in the pressman. The cause of this is that the proper center of a die with respect to the platen may not be its lineal center. What is here meant by the term "proper center" is the center of pressure, to determine which, in regular practice, is largely a matter of experience and judgment. Thus, to cite a simple example, if a die 6 ins. wide by 12 ins. long has twice the amount of line work in 6 ins. of its length than it has in the other, then this end will require twice as much pressure as the other; hence, to balance the strain upon the press, upon this basis of 2 : 1, assumed either as of pressure or of leverage, the transverse center of such a die should be 4 ins. from the end of its heavy surface.



EMBOSSING.
Fig. 18½

Still another reason why paper embossing involves very heavy pressure is that but one die is used; a fact, by the way, which is not infrequently unknown even by printers of experience. Thus, the real die, which is usually cut in steel or brass and occasionally etched in zinc, is a sunken figure, an intaglio, while that which would correspond to the "male" die is termed a "force" or "counter," and this is invariably built up artificially, as will be understood by reference to the diagram, Fig. 18½. In the construction of "forces" many substances are used, such as paper, with marine or

fish glue; waxes of various kinds, cements, shellac, clays, gutta-percha, fibers, hard rubber and the like. But it can be accepted as a principle that some kind of resilient substance is essential; for, even if it were practicable to produce a perfect metal "counter" (and this has been tried by electrical deposition), it would fail, because it is improbable that any machine can be built so rigid, under strain, but that it would act to cut the sheet. In this character of "make-ready" much depends upon the skill of the pressman; one man will produce a satisfactory result with 20 tons of pressure, where another man would hardly do more than indent the paper with 100 tons. The nub of the whole matter is to get the pressure into the recesses of the die.

Fig. 19 (Plate LXXIII) illustrates the writer's most recent design in this class of machine, and, although its platen dimensions are but 12¾ x 18 ins., the press weighs about 3 200 lbs. It is a solid mass of iron and steel. Figs. 20, 21, 22 and 23 should also be referred to in the following description.

The peculiarity which establishes the designation of this press, "eccentric action," is that the platen is actuated by eccentrics instead of cranks, these eccentrics being formed upon the inside faces of the gears and projecting inwardly through the main connecting rods, which latter are thus interposed between the finished side of the bed and the finished faces of the gear wheels, the space being just sufficient to permit free movement. In this wise the shafts and main connecting rods are brought to an almost perfect shearing strain, the impressional stress being applied with such directness as to avoid spring, end-thrust or side cramp. The gears, being outside of the rods, can thus be made of almost any desired diameter, permitting a high relation of single-pair gearing. The sides of the bed do not require to be recessed to receive the gears; hence, are carried out flush with the rods.

It is believed that this represents a fair approximation to what has been well termed "the anvil principle" in machine construction. The practical benefit to the embosser is the facility with which the job may be made ready, and its long life when so completed, as there is less tendency to "crawl," a fault which quickly breaks down the fine lines of the force.

The platen motion is similar to that of the printing presses, that is, a direct slide to the impression positively controlled by interlocking lugs. The extent of the direct motion is ⅝ in. But there is one im-

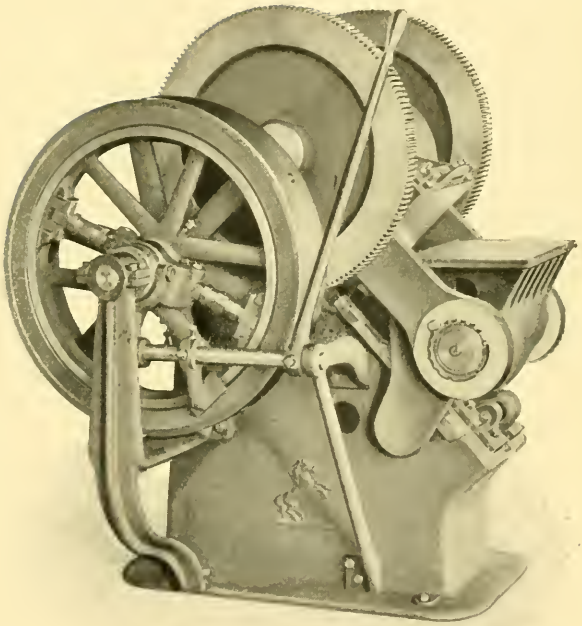


FIG. 19.—Eccentric Action Embossing Press.

portant modification. The rocker seats being inclined to an angle of 45°, the platen is thus virtually suspended by the connecting rods, the rockers sustaining but a portion of the weight of the platen. The rockers are developed from the center of the shaft. These conditions were all favorable to forming the bridge cam in such manner as to

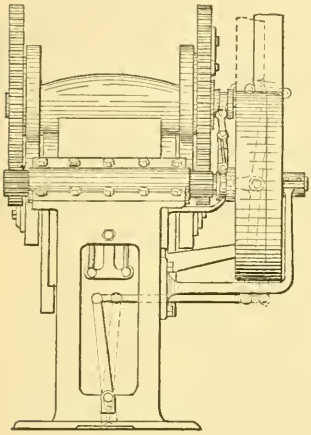


Fig. 20

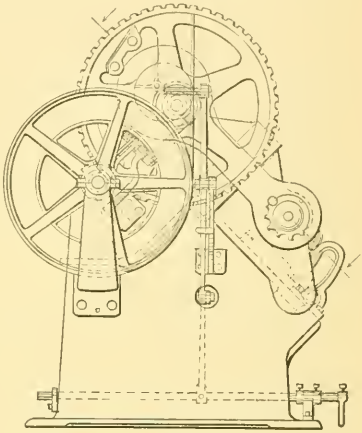


Fig. 21

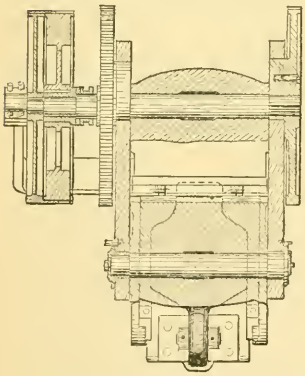


Fig. 22

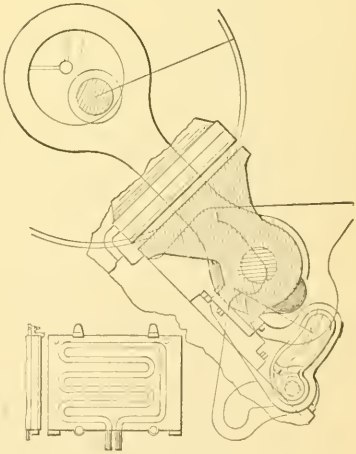


Fig. 23.

swing the platen differentially on its shaft in unison with the travel of the eccentrics, so that the "throw" of the eccentrics is augmented to the extent that the lower edge of the platen is carried outward in a line practically parallel with the face of the bed. Two important ad-

vantages are thereby obtained. First, the entire face of the platen is, as it were, lifted out and up to the feeder; and second, the radius of the eccentrics is reduced to a minimum, in this machine being but $2\frac{1}{8}$ ins. But for this design of the bridge cam the radius of the eccentrics would have required to be at least $3\frac{1}{2}$ ins.

The bridge in this press is also the platen, that is, instead of being made in two parts bolted together, one solid casting comprises the two functions. It is heavily ribbed to resist compression in front, with elliptical formation at the back to resist transverse and tensile strains.

The platen may be carried back or forth through a range of $\frac{1}{8}$ in. in 10 separate adjustments, by means of the eccentric sleeves positively locked to each connecting rod. Thus the center of strain through the platen is never altered by changing the rotative positions of the sleeves.

The bed is inclined forward to an angle of 45° from the vertical. The platen is caused to swing outward and upward to within 5° from the horizontal. In this manner the face of the platen presents itself to the operator like a table, and although 40° of swing is unusually short in a platen press, this machine is frequently fed at the rate of 1 800 impressions an hour.

The press is entirely self-contained, that is, every part is directly attached to the frame. The eccentrics are oiled from the outside of the gear wheels and the bridge-shaft trunnions through a slot in the bridge, consequently the connecting rods are not pierced. Oil reservoirs are formed in the gears, from which project oil holes to the bearing faces of the eccentrics, the consequence of this being that oil is fed at each revolution of the gears.

The pinions are cut solid, forming a part of the driving shaft, which is 3 ins. diameter and is mounted in a babbitted box extending across the frame. The main connecting rods are of liberal dimensions of mild forged steel.

There is a section of steel in each of the gear wheels, in which are formed the teeth that carry the eccentrics over the nip. This section is formed separately, is then placed in the mold and fused to the iron during the process of casting. The union of the two metals is usually perfect. The advantages of this construction are that the strength of the steel teeth is at least quite as great as would be obtained were the entire wheel produced from a steel casting, while in

the event of accidental breakage the wheel can be duplicated at much less expense. This mode of producing gear wheels for heavy impressional duty originated with the writer about 14 years ago, the Colt's Arms Company conducting the primary experiments, which resulted in complete success. Many hundreds have since been put into severe service without a single failure at the fuse or "weld" so far as he is aware. This is a feature which would seem to be applicable in many like cases. The construction was not patented, to the writer's frequent regret, and anyone is free to use it.

A steam blank, shown detached in Fig. 23, is fitted to the bed, the pipes pressing down, and thence back under the frame. This blank, the better to conduct the heat to the dies, is made of hard composition. It is usually arranged so that cold water may be turned on to cool off quickly. Occasionally the back of the blank is grooved to permit passage of air, acting to prevent, somewhat, the conduction of heat to the bed.

The friction clutch has proved highly effective. It is shown on Fig. 19, as recently designed and applied. The shifter handle is fitted with a brake shoe, so that, when the clutch is thrown off, relieving the press from the fly wheel and the belt, friction is at the same time applied to the web of the clutch mechanism, thereby stopping the platen at any desired position of its travel. The clutch may be operated with any degree of rapidity without danger of damaging the press, and without the slightest shock or jar in starting or stopping. But little novelty is claimed for this clutch, of which, possibly, the dominant feature is that, being a friction clutch and operating under excessively severe conditions (shock-transmission), it performs its function quite as perfectly as if a positive engagement were effected. A reason for this, it is believed, is that the parts are unusually heavy, and are constructed with a degree of accuracy not ordinarily followed out in such devices; consequently the power derived from the hand of the operator goes almost entirely into adhesive friction, little or none being absorbed in spring of parts.

Presses for Cutting and Scoring Paper Blanks Used in the Manufacture of Folding Paper Boxes.

The process of making folding paper boxes as now carried on may properly be designated not only a modern art, but a modern American

art, with which the writer has had something to do. Although the business, commercially, has reached an enormous volume, it is believed to be yet in its infancy, as the uses and adaptations, both of paper itself and the boxes made therefrom, are being constantly extended, covering all employments, such as water-proof paper for butter, raw oysters and ice cream, the higher grades for laces, candy and clothing, and those of strongest fiber for hardware, ammunition and the like.

Examples of paper-box blanks are shown in Figs. 24 and 25. The full lines represent cuts made by the steel rule, where the sheet is en-

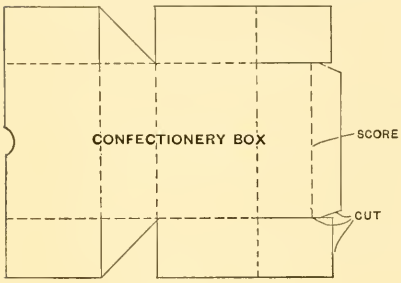


Fig. 24

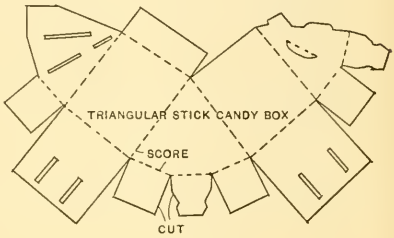


Fig. 25

tirely separated, while the dotted lines indicate the crease or kerf produced by the brass rule and upon which the blank is folded, to form a box. By this system the cut and the crease are produced at one and the same impression. One of the controlling advantages incident thereto is, that although the sheet may not be fed to exact register on the platen, the cut and score, with respect to each other, are bound to be as perfect as the die. Consequently, there is but little loss of stock as the result of careless feeding. A plurality of these blanks is usually formed at each impression, that is to say, from 2 to 20, or as many as can be disposed in a single sheet of the capacity of the machine, and this is one of the advantages inherent in a machine of large size, as the stiff, smooth paper used in box-making may ordinarily be fed nearly, if not quite, as rapidly in large sheets as in small.

The process is quite simple, consisting in setting and locking up in a chase pieces of steel and brass rule, properly disposed, to produce the desired form of blank. When so assembled it is termed a "die." The steel rule is used for cutting, and is sharpened, usually from both sides, like a "cold chisel"; the regular type-high standard—that is,

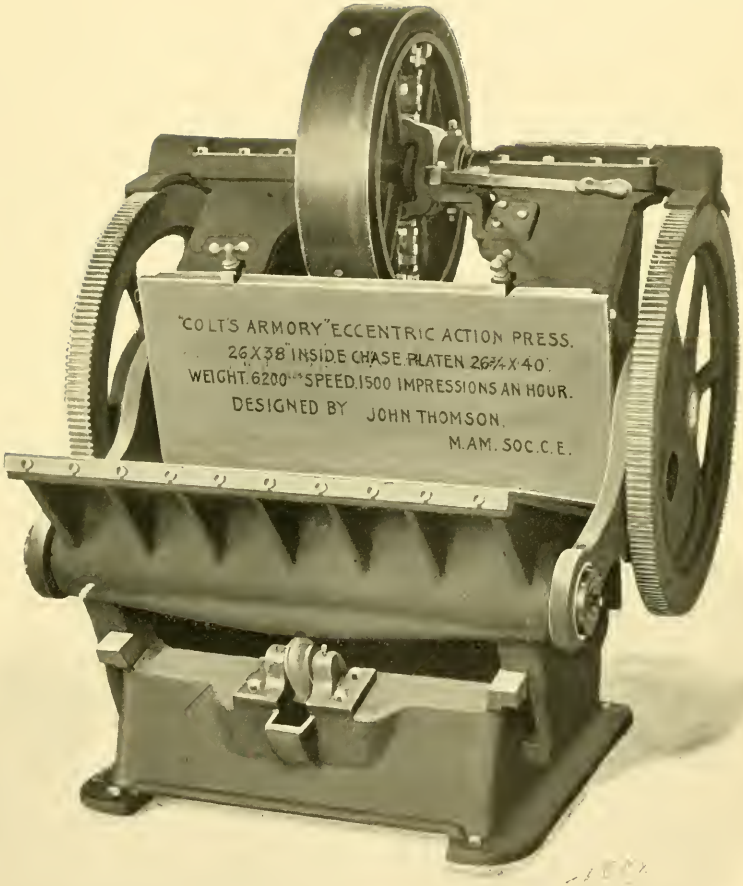
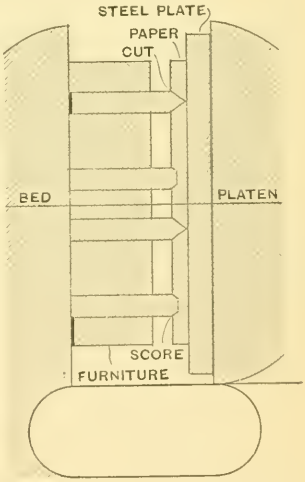


FIG. 27.—Eccentric Action Cutting and Creasing Press.

.92 in.—having come into use through the original employment of printing presses for the work. The brass rule is used for producing the crease or score, and is usually from .01 to .02 in. less in height than the steel rule. Its face may be left square or rounded, according to special requirements. The cut is made against metal plates, placed upon the surface of the platen. Tin, copper, brass, zinc, iron, steel, hard rubber and many of the fibers have been employed for this purpose, varying in thickness from $\frac{1}{32}$ to $\frac{1}{4}$ in., but the regular practice now is to use ground steel plates $\frac{1}{8}$ in., $\frac{3}{16}$ in. or $\frac{1}{4}$ in. thick. The term "ground," in this connection, means that the plates are finished bright, as in circular saws. The grade of steel is usually referred to as "soft" or "medium" saw plate.

The steel cutting rules are usually not tempered, but are planed, milled or filed, and then slightly run over by an oil stone to remove the wire edge. The quality of this material is usually designated as "hard cold-rolled spring steel."

The diagram, Fig. 26, may assist to an understanding of the principal feature of this process. Here, as in letterpress printing and embossing, the skill of the pressman is quite as essential to success as that he who handles a transit should understand how to adjust it as well as to take its readings.



PAPER-BOX CUTTING AND SCORING OR CREASING.
Fig. 26

Fig. 27 (Plate LXXIV) illustrates the latest, and probably the strongest, most rigid and largest platen machine of the jobbing pattern that has yet been designed. As it exemplifies the principles already pointed out in the embossing press, but one or two special features will be described. Thus, as shown in the engraving, the fly wheel is mounted upon the top of the bed between the gear wheels. The advantages of this disposal are increased compactness, a perfect division of the strain to the gears, and the ability to mount the clutch handle directly in front of the feeder. The bed is inclined 15°; hence, the rockers of the bridge roll back and forth upon an inclined plane. The object of this is to

bring the platen face further out, to facilitate the more rapid feeding of large sheets. These machines are frequently operated at the rate of 1 500 impressions an hour, an interval between impressions of slightly less than 2.5 seconds. The weight of the platen is 1 300 lbs., and at each reciprocation it moves through an angle of about 60°. The weight of all the parts in motion is about 2 500 pounds. The platen, to all ocular intents and purposes, may be instantly stopped and started, either during its inward or outward action, without the slightest shock or tremble.

Fig. 28 (Plate LXXV) illustrates the crank action type of paper-box cutting and creasing presses. This is a case in which "the first shall be last," for chronologically, this was the first machine of the "Colt's Armory" line of presses designed by the writer, the drawings for which were made during the winter of 1886. There was a number of things in connection with the production of this machine which was particularly gratifying. This was the first practical application of the new platen-controlling device; it was the largest platen, at that time, 21 x 32 ins., and its weight, 1 100 lbs., was nearly twice that of any prior machine of its kind; the eccentric sleeves used for throwing off the impression required to be secured to the bridge by double latches and yet to be readily detachable by one hand. Moreover, it would not be a commercial success unless it operated satisfactorily at 1 200 impressions an hour. Then, over all, the machine had been founded upon this theory, namely, if, for the work to be performed, it could be made practically inelastic, to the extent at least of ensuring simple contact and no more, between the edge of the knife and the surface of the cutting plate, then the durability of the dies would be greatly enhanced over prior practice. It may serve to make clear the importance of reaching such a condition by mentioning that a fault or spring under strain of but .001 in. in one impression becomes the equivalent of 1 in. in 1 000 impressions, and so on. Suffice it to say, that the first press built from the drawings not only met every condition predicted and served its intended purpose thoroughly well, but has also since stood as a model, both at home and abroad, for the kindergarten professors of the art. The writer may say that the first time he saw this press operating at actual work, in a New York City factory, it was being fed at 2 400 impressions an hour, that is, exactly double the speed originally contemplated. The result of this inspection was to

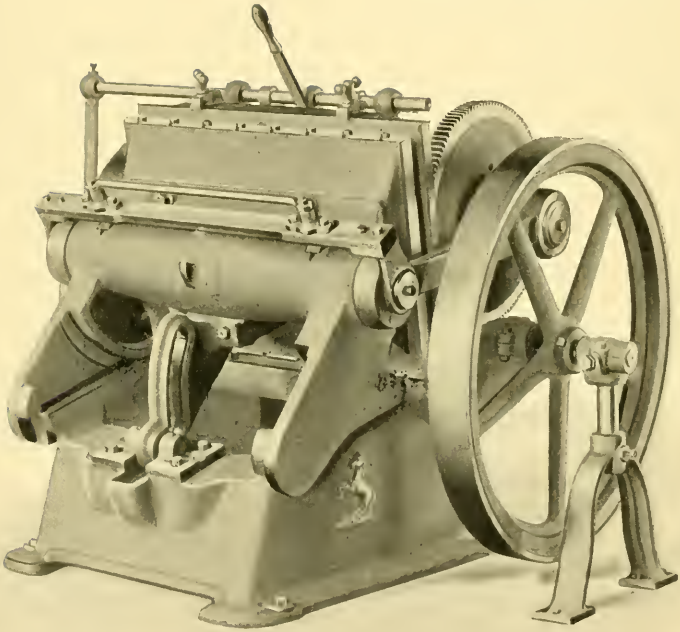


FIG. 28.—Crank-Action Paper-Box Cutting and Creasing Press.

induce that blessed feeling of satisfaction which comes to one when he has the ocular demonstration that his theory is being "sustained by practice."

MISCELLANEOUS FEATURES, WITH SOME EXPERIENCES AND OPINIONS.

The beds and frames of the presses here illustrated have been the subject of rather protracted study. As samples of decorative art work they undoubtedly are not entitled to take high rank, for each and every line has been laid subservient to but one objective—efficiency. To the writer's mind, a curly-cue line in the path of a strain is an abomination. And this reference to plain lines reminds him of a youthful experience when he was commissioned to design the case for an exceptionally fine watch movement to be presented to the daughter of the lady making the purchase. The specification closed like this: "In fine, I want the case to be as I hope the recipient will become—the outside not remarkable except as it reveals the goodness within." Upon the whole, when you follow up the logic of the question, should not efficiency come pretty near to being the real objective of the artist as well as of the engineer?

As will doubtless have been noticed, the plotting of the rocking platen motion by the graphic method would be, to say the least of it, troublesome and tedious. The writer early in the work adopted the use of paper templates, carefully marking thereon, or perforating, as the case might be, not only the essential working centers, but frequently noting arbitrary positions. Then, as the curve would be rolled, or differentially rolled and slipped upon the straight edge (this, too, usually being paper made fast to the board), the position of the several centers would be marked and given a corresponding number or letter. In this manner the work could readily be proven with accuracy while a great variety of cut-and-dry locations were easily laid out, and that, too, with considerable rapidity.

Here is a simple rule to avoid accidental breakage in machinery. Make it a hard and fast practice to have your machinery examined at stated times, and particularly observe that all stud-bolts, screws and nuts are tight and performing proper duty. Insist upon the carrying out of this simple system, and you will find that those accidents which are reported as if an effect without a cause, "broke itself, not a thing touched it," will cease; for if it had been "touched" at the proper

time, there would have been no cause for accident. The economics of railroading compels such inspection of cars and locomotives. Then it has been proved, times over, that it pays to keep machinery bright and clean, and while this is particularly applicable to a printing press, it is good practice, now and then, even in a stone crusher.

An elementary word in regard to oil may bear repeating here. The function of oil on machinery is to prevent the contact of metallic surfaces. It acts like a system of rollers. To perform proper duty, it should have sufficient tenacity not to crush; it should be sufficiently limpid to reach the surfaces of well-fitted journals and yet not "run away"; and it should not change its quality by exposure to the air or from contact with metals. Animal oils are liable to corrode; vegetable oils to "gum up." The writer does not hesitate to recommend the modern mineral oils, without doctoring or compounding in any way, as the best for regular practice, at least in the character of machinery herein referred to. If some one could devise a thumb-and-finger rule for determining the approximate quality of oil, and then promulgate it, there would result at once a distinct advance in moral ethics; for the patience of the patriarch of the land of Uz would give out under the complaint of "soft metal" when it is found that bearings subjected to tons of pressure to the square inch are being lubricated with oil proper only for a sewing machine or a clock.

Respecting the application of oil, it is better practice to apply frequently and sparingly rather than at long intervals to flood your bearings. All bearings subject to heavy strain should be frequently wiped, if open, or washed out with benzine, if closed, else the fine particles of metal which become separated, mix with the lubricant and thus form a grinding paste. And especially is this so in the first starting up of a new machine, in which there is sure to be a residuum of fine dust, filings and grit that no amount of original wiping or brushing will fully remove. Now, if this is carefully removed as rapidly as it accumulates, then the effect of the initial wear is highly beneficial, the bearings soon taking on a burnished polish, the endurance of which is of the first order.

In all closed cams, that is, in which a closely fitted roller works in a groove, oil should be sparingly applied, especially so if the oil is of heavy body, the reason for this being that the oil may act to prevent the roller from turning upon its journal.

It has proved advantageous in our practice to form all cam rollers slightly crowning. In this way, the pressure is bound to be transmitted evenly to the stud or journal, and it will be more certain to revolve under all circumstances.

It is believed that, wherever practicable, all friction rollers and crank-pin bearings and the like ought to be freely fitted sidewise, that is, having plenty of end motion, as under such conditions there is less liability to cut, or "ring up," than where no opportunity is given for the bearing surfaces to shift automatically. It is probable that a principal reason why end motion shows up, practically, as well as it does, is that it assists to distribute the oil between the working surfaces.

The query is often asked : What pressure will this or that machine give ? Such questions cannot be definitely answered, it is believed, at the present time. Several years ago the writer constructed a hydraulic ram adapted to a printing press to be acted upon by the platen, its relation being 50 : 1 of a 10 000-lb. Bourdon spring gauge, alleged to have been carefully constructed for the purpose, and intended to give a maximum indication of 500 000 lbs. But the shocks soon gave evidence that the gauge tube was playing the too usual part of such instruments, and this, together with business complications, which came up at the time, put a stop to the proposed extended series of experiments. Nevertheless, enough was ascertained by the considerable number of experiments carried out to indicate a "handy" empirical method of approximating the measure of kinetic energy, in terms of foot pounds, which the fly wheel of a press would be capable of exerting upon the platen, the sole object of this being to form a premise upon which to determine the dimensions of the working parts. The indications of the experiments referred to were that the coefficient of friction, under heavy strains, was materially higher and more variable than had been expected ; hence it appeared that any expression as to its value, short of absolute determination, under actual working conditions, would be little better than guesswork. The scheme was then adopted to disregard entirely the consideration of friction and simply let it stand as the factor of safety. Briefly, then, the whole matter boiled down to this : The pressure deliverable at the platen in foot-pounds (F) would be equal to half the weight of the rim of the fly wheel in pounds ($\frac{1}{2}$ M) times the square of the velocity (v^2) in feet per second at the center of its gyration divided by the impression

movement of the platen in parts of a foot, the latter most readily obtainable by finding the versed sine (S) of the crank during the angle of its impression action $\left(F = \frac{\frac{1}{2} M V^2}{S}\right)$. Thus, if it were shown that the theoretical strain which might be imposed upon the connections were up to about the tensile limit of the material, then the power absorbed in friction, be it 25, 35, 50% (any of which guesses might be good), would be the factor on the side of safety. The diagram, Fig. 29, is a reduplication of the dimensions, process and figures upon

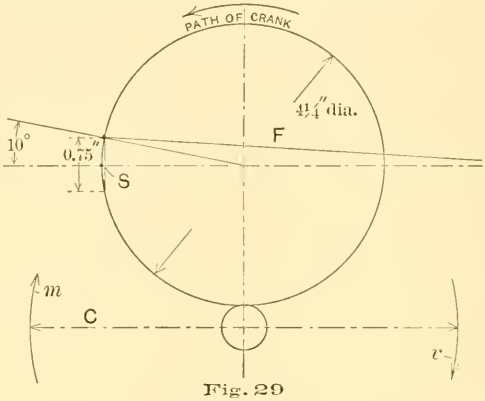


Fig. 29

Dimensions are those of Embossing Press, Fig. 19. Example: F = foot-pounds on connecting rods. S, versed sine, = .00275 ft. M, fly wheel, = 250 lbs. C, center of gyration of fly wheel, = 6.28 ft. circumference. V, velocity of fly wheel, = 17.8 ft. a second. Relation of fly wheel to crank = 8.5:1. Time of revolution of crank = 3 seconds. Cross-section of connecting rods and pins = 20 sq. ins. $\left(F = \frac{\frac{1}{2} M V^2}{S}\right)$. Thus, $125 \times 17.8^2 = 1\,440\,181$ ft. lbs., or 720 tons, if no friction, and if fly wheel were brought to rest during the 10° traverse of crank. (= .083 second).

But assume belt capable of restoring but half of full velocity, then $\frac{360}{20 \text{ sq. ft.}} = 18$ second foot-tons to each square inch of section; which is probably the greatest maximum load possible in practice and with no deduction yet made for friction.

which the embossing press, Fig. 19, was designed, and the other machines herein shown were also predicated upon this theory. All the writer will say for this method is, that the presses built under its wing have most worthily stood up to their duty. His judgment is that it is well within the line of safety, in the character of machines here shown, as in at least two instances fly wheels were subsequently increased in weight over that called for by the rule, again indicating a very high coefficient of friction under strain. Whether there is any novelty in this direct transfer from the rim of the fly wheel to the versed sine of

the crank, he does not know, nor does he much care, as, like many such expressions, it is largely an intellectual satisfaction, liable to be practically misleading. He hopes, at no far distant time, to take the subject up under the only proper method, if it can be satisfactorily worked out, as he confidently believes it can, namely, to make the measurement of the pressures in actual pounds of weight at the apex, the instant of greatest effort.

Conclusion.

The strongest incentive to advancement is to learn of the achievements made by others, and next to this is the faith of those with whom you have to treat; for it not only requires skill and experience, but patience, faith and money as well, to make a commercial success of any machine which is expensive to construct as compared with its competitors. Intention is, of course, a useful factor; but this is not all. You must first know what to do; next, how to do it, and then do it. We should all bear in mind that an incorrect principle will outlive the best steel that was ever forged. And then, too, the "little things" are so often of the most vital importance, because far reaching in their consequences. It is the obscure detail, unrecognized or passed by as of no consequence, which most often stands as the dividing line between that which shall be successful and enduring, or unsuccessful and short-lived. It was the great anatomist, sculptor, architect, painter, Michael Angelo, who said "Trifles make perfection."

Whatever may be here discovered to be defective, or whatever may be regarded as worthy, the writer is entirely responsible for; but that the early work was under any circumstances possible was due to the loyal good faith and judgment of his early associates and friends in the work, who were then officers in the Colt's Arms Company, namely, General William B. Franklin, M. Am. Soc. C. E., its Vice-President and General Agent; Mr. Hugh Harbison, its Treasurer, and the late Horace Lord, who for over thirty years was its Superintendent.

It is hoped that the engraving here presented, "The Iron-Worker and King Solomon,"* will not be regarded as out of place, as it is in-

*Permission to make this reproduction, from one of the first artist's proofs of this celebrated engraving, was specially given to the author by the owner of the copyright for the express purpose of presentation to the members of the Society. It was at first intended to bind it in as a part of the *Transactions;* but with the view to preserve the margin better and to permit the use of heavier paper it has been decided to send it out as an insert.

tended to indicate the most advanced accomplishment in photographic "process" work and also in letter-press printing. The subject is not only happily chosen, we believe, but every detail, mechanically and artistically, is faultless. Results like this might possibly cause an improper degree of exultation upon the part of the modest press-maker were it not for the restraining claims of the ink-maker, the paper-maker, the photographer, the artist and the pressman, each and all of whom are entitled to share in the credit. Nevertheless, may he not properly take unto himself the claim, that without the printing press there would have been no Art Preservative of Arts; nay, more, that without the engineer there would have been no printing machine? Verily, we have eminent authority for this assumption, for the wisest man, when time was young, proclaimed it in express words: "Ho, there," commanded Solomon, "make place at my right hand; the claim is justly made; but for the iron-worker (the engineer) I would have had no temple!"

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THE STRENGTH AND WEATHERING QUALITIES OF ROOFING SLATES.

By MANSFIELD MERRIMAN, M. Am. Soc. C. E.

READ DECEMBER 19TH, 1894.

In a paper published in *Transactions* for September, 1892, Vol. XXVII, pages 331–349, the soft-veined roofing slates of Northampton County, Pa., were described, and results of tests of strength and weathering qualities were presented. Similar tests of other varieties of slate, and also a series of comparative impact experiments, having since been made, the following additional notes are given as a continuation of the discussion of the subject.

The increasing growth of the slate industry in the United States is shown by the following figures taken from the census reports:

	In 1880.	In 1890.
Number of quarries	94	206
Capital invested	$3 328 150	$10 042 293
Squares of roofing slate produced	457 267	828 990
Value of all slate produced	$1 529 985	$3 444 863

The distribution of the industry among the different States in 1890 is thus indicated: The value of all slate produced in Pennsylvania was $2 011 776; in Vermont, $838 013; in Maine, $214 000; in New York, $130 603; in Maryland, $110 008; in Virginia, $85 079; in Georgia,

$15 330; in Michigan, $15 000; in California, $13 889; in New Jersey, $10 985 ; in Arkansas, $240 ;—total, $3 444 863.

A more natural classification is that by regions, in each of which a quality of slate, more or less distinctive, is found. The region furnishing the most slate is that in Rutland County, Vt., and Washington County, N. Y., the product of which is largely purple, green and red slates. The other regions produce bluish black slates almost entirely. The following shows the number of quarries and the value of the product in each region in 1890.

	Quarries.	Product.
Vermont and New York region	76	$968 616
Bangor region, Pennsylvania	20	707 162
Lehigh region, Pennsylvania	45	690 432
Pen Argyle region, Pennsylvania	17	393 030
Maine region	4	214 000
Northampton hard-vein region, Pennsylvania	18	184 595
Peach Bottom region, Maryland and Pennsylvania	9	146 565
Virginia region	3	85 079
Other regions (Arkansas, California, Michigan, New Jersey, Georgia)	14	55 384
	206	$3 444 863

The physical and chemical properties of the slates of the Bangor and Pen Argyle regions are described in the paper of 1892. These, together with the Lehigh and the Northampton, hard-veined slates, are found in the extensive slate formation known as the Hudson River division of the lower Silurian deposits, which extends from New Jersey to Georgia along the southwestern slope of the Blue Mountains. The slate formations of Vermont and New York, of Maine, and of the Peach Bottom region, however, probably belong to the Cambrian division of the Archean or Azoic deposits, whose place in the geological series is lower and older than the Silurian rocks.

Vermont and New York Region.—This region is about 40 miles long, extending from Castleton, Vt., to Salem, N. Y., with an average width of about 1½ miles. Red slate is produced in Washington County, N. Y., and purple, green and bluish black varieties throughout the entire region, which are used, not only for roofing, but also for mantels and other ornamental purposes. In *Van Nostrand's Magazine* for August,

1884, are given the records of compressive and flexural tests made by J. Francis Williams, C. E., on blocks 1 in. in section. Wood and pasteboard cushions were placed between the bearing surfaces in some tests, the compressive strength being found greater than when no cushions were used. The mean results of these experiments are as follows, all values being given in pounds per square inch. The modulus of rupture is the mean computed from the breaking loads given for two different spans.

	Purple.	Red.	Green.
Compressive strength, wood cushions.....	19 380	14 170	13 140
Compressive strength, pasteboard cushions.	24 760	18 110	17 560
Compressive strength, no cushions.....	13 860	10 190	8 040
Elastic limit, no cushions.....	10 260	4 850	5 150
Modulus of rupture.....	10 800	7 310	8 840

Some impact and acid tests on the red slate of this region are described later in this paper.

Peach Bottom Region.—Of the nine quarries in this region, five are in Harford County, Md., and four in York County, Pa. The belt is about 8 miles in length, and its workable width about ½ mile; about 2 miles of this length are in Lancaster County, Pa., where, however, no quarries are now worked. The rough geological section in Fig. 1 shows the rock formations for about 50 miles in length parallel to the

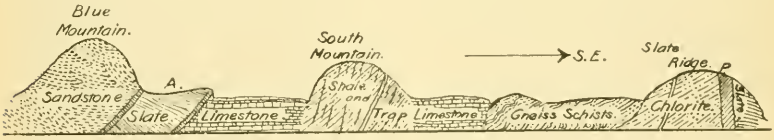

Fig. 1.

Susquehanna River, from the Maryland line to the Blue Mountains, north of Harrisburg. At *A* are the Hudson River slate deposits, which, however, have no quarries in this vicinity, and the Silurian limestone is found on both sides of the South Mountain. The Cambrian gneiss and chlorites occur further south, and at *P* is seen the narrow and almost vertical vein of Peach Bottom slates, in the hills known as Slate Ridge.

On the west side of the Susquehanna, about 5 miles from the river,

the slate outcrops on the surface. A little was quarried about the year 1800, and a stone church near Delta, Pa., was roofed with it in 1805, the slate remaining on the roof until 1893, when the church was pulled down, and the slate was sold for use on other buildings. The quarries now worked have been opened and developed since 1850; they are all open vertical pits, of various depths between 100 and 200 ft. The vein of workable slate is about 250 ft. wide at the eastern end, and nearly ¾ mile wide at the western end, the length being 3 or 4 miles.

The cleavage of these slates is nearly vertical and almost coincident with the dip, it being also parallel to the planes of stratification. The beds of clay were therefore subject to pressure normal to the planes of stratification, and the whole mass was turned into a vertical position by some violent upheaval in early geologic time. Hence ribbons do not occur in the slate of this region.

The methods of quarrying, splitting and dressing these slates are, in general, similar to those employed in the Northampton region. Quarrying is often interrupted by the inflow of water after rains. On Plate LXXVI is shown an abandoned quarry, in which on both sides are seen the so-called "joints," or splits in the rock. The joints are normal to the vertical cleavage and dip, while the "grain" of the slate is approximately at right angles to them. It appears as if the pressure from powerful horizontal forces upon the vertical vein of slate had caused tensile and compressive forces in inclined directions, the former resulting in the formation of joints, while the latter caused the grain. In quarrying, horizontal holes are drilled normal to the cleavage and in a row parallel to a joint, so as to detach a large block, perhaps 15 ft. long, 8 ft. wide and 4 ft. thick, which is split into several smaller ones before being hoisted to the surface. In splitting and dressing the roofing slate, it is always done so that the grain runs parallel to the longer side of the rectangle. This grain, although never so marked as that in timber, has a similar effect upon the strength in different directions, a piece of roofing slate being, for example, far more liable to crack lengthwise than transversely.

The compressive strength of Peach Bottom slate, as determined in 1893 by Prof. Louis E. Reber, of State College, Pa., from tests of 3-in. cubes, is 5 360 lbs. per square inch when the pressure is applied parallel to the cleavage, and 10 530 lbs. per square inch when the pressure is applied perpendicular to the cleavage.

PLATE LXXVI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXII, No. 741.
MERRIMAN ON ROOFING SLATES.

During the present year the writer has made tests for strength, toughness, density, softness, porosity and corrodibility on twelve specimens of Peach Bottom slate, following the same methods as described in the former paper for the old Bangor and Albion slates. The specimens were 12 x 24 ins. in size, varying in thickness from 0.21 to 0.29 in. For the test of strength they were laid on supports 22 ins. apart and broken by a load slowly applied at the middle. The modulus of rupture for each case was then computed from the formula—

$$\text{Modulus} = \frac{3 \times \text{breaking load} \times \text{length}}{2 \times \text{width} \times \text{square of thickness.}}$$

For instance, the specimen marked Q_1 was 12.04 ins. wide, 22 ins. between supports, 0.26 in. thick, and it broke under a load of 283½ lbs.; hence its modulus of rupture is 11 490 lbs. per square inch. The deflection, measured at the moment of rupture, was also noted as an index of toughness.

The density of the specimens was determined by finding the specific gravity of each. The degree of softness was found by the weight abraded by 50 turns of a small grindstone under a constant pressure of 10 lbs. The porosity was determined by finding the percentage of water absorbed in 24 hours, after being dried for the same length of time at a temperature of 135° Fahr. The test for corrodibility was the percentage of loss in weight after immersion for 63 hours in a solution consisting of 98 parts by weight of water, 1 part of hydrochloric, and 1 part of sulphuric, acid.

The color of the slate was a dark bluish gray, or bluish black, and the texture of the surface was slightly scaly and soapy, being less smooth than the Northampton varieties. When ruptured by flexure, the specimens broke square across the grain without splitting or lamination. The tests for density, softness, porosity and corrodibility were made on pieces of the ruptured specimens.

The table on page 534 gives the results of all the tests for each of the 12 specimens and also the mean values.

An examination of these results tends to confirm the conclusions announced in the previous paper that in general the strongest specimens are the heaviest and softest, as also the least porous and corrodible, although exceptions occur in the case of Q_7 and P_2, and the Q specimens seem more corrodible than the P's, although greater in strength. The tests for strength and corrodibility are probably those

Mark of Specimen.	Strength. Modulus of rupture in pounds per square inch.	Toughness. Ultimate deflection in inches on supports 22 ins. apart.	Density. Specific gravity.	Softness. Grains abraded by 50 turns of a small grindstone.	Porosity. Percent. of water absorbed in 24 hours	Corrodibility. Percent. of weight lost in 63 hours in acid solution.
Q_1	11 490	0.32	2.886	69	0.265	0.247
Q_2	12 585	0.30	2.907	115	0.197	0.197
Q_3	8 400	0.30	2.900	110	0.304	0.291
Q_4	13 430	0.32	2.893	177	0.228	0.194
Q_5	8 320	0.28	2.900	75	0.264	0.237
Q_6	12 010	0.32	2.918	67	0.209	0.200
Q_7	14 210	....	2.890	111	0.278	0.341
Q_8	13 060	0.34	2.902	67	0.261	0.240
P_1	10 520	0.24	2.912	69	0.171	0.150
P_2	9 360	0.20	2.885	53	0.143	0.226
P_3	10 470	0.34	2.858	87	0.216	0.161
P_4	11 255	0.26	2.873	80	0.155	.....
Means....	11 260	0.293	2.894	90	0.224	0.226

of greatest importance in forming an opinion regarding the value of the slate under actual conditions of service. The test for softness, although a good one for a single lot of specimens, may not serve to fairly compare lots tested at different times on account of the varying condition of the grindstone.

The chemical composition of the Peach Bottom slates is shown by the following analyses, one made by the Geological Survey of Pennsylvania in 1877, and the other by Booth, Garrett & Blair, of Philadelphia, in 1885:

Geological Survey.		Booth, Garrett & Blair.	
Silicic acid (SiO_2)	55.880	Silica	58.370
Alumina (Al_2O_3)	21.849	Alumina	21.985
Ferrous oxide (FeO)	9.034	Protoxide of iron	10.661
Water (H_2O)	3.385	Water	4.030
Potash (K_2O) and soda (Na_2O)	4.100	Alkali	1.933
Carbon (C)	1.974	Carbon	0.930
Magnesia (MgO)	1.495	Magnesia	1.203
Lime (CaO)	0.155	Lime	0.300
Sulphuric oxide (SO_3)	0.022	Sulphur	0.107
Titanic acid (TiO_2)	1.270	Titanic acid	traces
Manganous oxide (MnO)	0.586	Oxide of manganese	traces
Iron bisulphide (FeS_2)	0.051	Carbonic acid	0.390
Cobaltus oxide (CoO)	trace		
	99.801		99.909

The valuable constituents in slate are the silicates of iron and alumina, while the injurious constituents are sulphur and the carbonates of lime and magnesia. The percentages of these in the two analyses are as follows:

	Geological Survey.	Booth, Garrett & Blair.	Mean.
Silicates of iron and alumina.....	86.763	91.016	88.889
Sulphur	0.039	0.107	0.073
Carbonates of lime and magnesia...	3.319	3.066	3 192

The slates of the Cambrian formation are usually regarded as better in respect to strength and weathering qualities than those of the Silurian age, the market price of some varieties of the former being, indeed, more than double that of the common kinds of the latter. The Northampton slates investigated in the former paper take a high rank among the Silurian kinds, while the Peach Bottom specimens may be regarded as a good representation of the dark-blue Cambrian varieties. The following tabulation, giving the mean results of the series of tests of both, may hence be taken as the best comparison possible at present of the average physical properties and chemical composition of the Silurian and Cambrian dark-colored slates of Pennsylvania.

PROPERTY.	MEASURED BY—	SILURIAN.	CAMBRIAN.
Strength	Modulus of rupture, in pounds per square inch.....	8 480	11 260
Toughness.....	Ultimate deflection, in inches, on supports 22 ins. apart.....	0.291	0.293
Density	Specific gravity.....	2.777	2.894
Softness.....	Grains abraded on grindstone under stated conditions	104	90
Porosity.....	Percent. of water absorbed in 24 hours.....	0.191	0.224
Corrodibility...	Percent. of weight lost in acid solution in 63 hours..	0.496	0.226
Valuable Constituents.	Silicates of iron and aluminum, percent.....	81.88	88.89
Injurious Constituents..	Sulphur, percent.....	0.58	0.07
	Carbonates of lime and magnesia, percent.....	12.59	3.19

With respect to the relative value of physical tests and chemical analyses, it may be said that while the latter are valuable, the former can alone be regarded as giving authoritative information as to the wear of slate under actual conditions. The strength and weathering qualities of slate or stone depend, not merely upon its chemical constituents, but on the manner in which the grains are cemented together. For the determination of this a microscopic inspection is necessary, and in the absence of such the physical tests seem to carry far greater weight than the chemical analyses.

Impact and Acid Tests.—While the preceding methods of testing are readily carried on in the laboratory, they are not easily made under conditions of actual practice on account of the absence of precise weighing apparatus, and the lack of time and skill. It seems desirable that a test for slate should be devised which can be quickly applied by an architect or builder, and be used with confidence. An impact test, made by simply dropping a ball, appeared one likely to yield good results, and accordingly a series of experiments has been carried on to determine what can be done in this direction. In connection with these, a series of severe acid tests has been made on the same specimens.

Seven varieties of slate were used in these experiments. Four, designated hereafter by the letters *C*, *D*, *E* and *F*, were Silurian slates of Pennsylvania. Three were Cambrian slates, *P* and *Q* being Peach Bottom specimens, and *V* being a red slate from the New York and Vermont region.

The pieces of slate used in the impact test were 6 x 7¾ ins. Each piece was placed with the ends loosely clamped in grooved supports, so that it was approximately in the condition of a beam with fixed ends, the length between edges of supports being about 7¼ ins. and the width 6 ins. A wooden ball weighing 15.7 oz. was dropped upon the middle of the slate from a height of 9 ins., and the number of blows required to produce rupture was noted. The number of foot-pounds of work per pound of slate, expended in causing rupture, is a measure of the ultimate resilience of the material or of its capacity to resist shock, and thus is an index, both of its strength and toughness. Five specimens of each kind of slate were thus tested, and the table on page 537 gives the individual results and means.

The acid tests were purposely made severe in order to obtain, if possible, a better idea of the resistance to corrosion than is given by the previous tests of 63 hours. Seven jars containing a solution of 1 part of hydrochloric acid, 1 part of sulphuric acid, and 98 parts of water, by weight, were prepared, and, in each, two specimens of each variety of slate were immersed for 120 hours, or five days, the solution being well stirred once a day. The specimens were then taken out, dried for 40 hours, weighed, and the loss of original weight determined. The solution was next strengthened by adding the same amount of the two acids, and the specimens were replaced for another 120 hours, after

Silurian Slates.					Cambrian Slates.				
Specimen.	Thickness. Inches.	Weight. Ounces.	Number of Blows.	Foot-pounds of work per pound of slate.	Specimen.	Thickness. Inches.	Weight. Ounces.	Number of Blows.	Foot-pounds of work per pound of slate.
C_1.....	0.21	13.8	6	5.12	P_1	0.26	17.3	9	6.13
C_2.....	0.19	12.9	4	3.65	P_2	0.26	17.2	15	10.29
C_3.....	0.22	13.8	5	4.27	P_3	0.31	20.4	55	31.74
C_4.....	0.20	12.8	7	6.62	P_4	0.28	18.4	52	33.35
C_5.....	0.23	15.6	10	7.56	PP_4 ...	0.29	20.4	68	39.33
Means ...	0.21	13.8	6.4	5.44	Means..	0.28	18.7	39.8	24.17
D_1	0.19	13.0	5	4.53	Q_1.....	0.26	17.2	11	7.54
D_2	0.22	14.5	7	5.69	Q_2.....	0.27	17.8	20	13.25
D_4	0.19	12.4	3	2.85	Q_3.....	0.29	19.3	17	10.39
D_9	0.22	14.8	7	5.58	Q_7.....	0 28	18.2	6	3.89
D_{11}	0.24	16.2	6	4.37	QQ_7....	0.27	17.6	11	7.37
Means ...	0.21	14.2	5.6	4.60	Means..	0.27	18.0	13.0	8.49
E_1	0.19	12.4	4	3.63	V_1	0.21	13.0	32	29.04
E_{14}	0.20	13.5	2	1.74	V_2	0.26	17.3	215	146.65
E_{18}	0.21	13.5	4	3.50	V_3	0.21	12.9	339	310.09
E_{20}	0.19	13.0	6	5.44	V_4	0.20	12 9	55	50.31
E_{13}	0.22	14.3	5	4.12	V_5	0.25	14.2	117	97.22
Means ...	0.20	13.3	4.2	3.68	Means..	0.23	14.1	151.6	126.66
F_2	0.22	14.4	4	3.27					
F_4	0.20	13.3	3	2.66					
F_6	0.22	14.7	5	4.01					
F_7 .	0.25	16.5	7	5.00					
F_8	0.20	13.7	3	2.58					
Means ...	0.22	14.5	4.4	3.50					

Size of Specimen..... 6 x 7¾ ins.
Weight of Ball.....15.7 ozs.
Height of Fall..... 9 ins.

which they were dried and weighed again. The solution was again strengthened by the addition of the same amounts of acid, and the specimens were immersed for 120 hours, after which they were dried and weighed as before. The specimens used for this purpose weighed about 1½ ozs. each, and the scales were sufficiently delicate to detect ½ grain. With two exceptions, they were parts of the pieces which had previously been broken in the impact tests.

In the following table the percentages of loss of original weight at the end of the three periods are given, the specimens being arranged in order of corrodibility, and also in the last columns the mean foot-pounds of work per pound of slate required to cause rupture by impact, and the mean specific gravities. These figures show that the specific

gravity is not a good index of corrodibility, but they plainly indicate that the least corrodible slate offers the greatest resistance to impact, although there are slight exceptions in the case of *D* and *E*. The diagram in Fig. 2, where the work of resilience is plotted as an ordinate and the mean loss of weight as an abscissa, shows this clearly to the

Specimens.	Percentages of Loss of Weight.			Foot-pounds of work per pound of slate.	Specific gravity.
	After 120 hours.	After 240 hours.	After 360 hours.		
D_2	1.06	1.94	2.74		
D_9	1.22	1.94	2.79		
Mean	1.14	1.94	2.76	4.6	2.77
F_7	1.08	1.60	2.18		
F_9	1.43	2.47	2.98		
Mean	1.25	2.03	2.58	3.5	2.77
E_{18}	0.82	1.36	1.82		
E_{20}	0.88	1.48	2.09		
Mean	0.85	1.42	1.95	3.7	2.78
C_2	0.64	1.28	1.70		
C_5	0.54	1.10	1.66		
Mean	0.59	1.19	1.68	5.4	2.78
Q_3	0 45	0.90	1.27		
Q_5	0.40	0.99	1.32		
Mean	0.42	0.94	1.29	8.5	2.90
P_3	0.32	0.81	1.12		
P_4	0.28	0.93	1.10		
Mean	0.30	0.87	1.11	24.2	2.89
V_4	0.00	0.17	0.34		
V_5	0.00	0.09	0.17		
Mean	0.00	0.13	0.25	126.7	2.81

eye for each of the periods of immersion. With regard to the progress of the corrosion with time it appears that the two are approximately proportional. A marked change in color of the Silurian specimens was noted, the dark blue becoming a grayish white after the last immersion, while but a slight change appeared in *Q*, and *P* and *V*

remained almost unaffected. Change in color is thus a direct index of corrodibility, both being due to the same cause.

As the result of the investigations thus far made, it may be concluded that the tests for density and softness, although of importance for slates of the same locality, are not good indications of the strength and weathering qualities of those of different regions; that the tests for porosity, corrodibility and flexural strength give good indications of

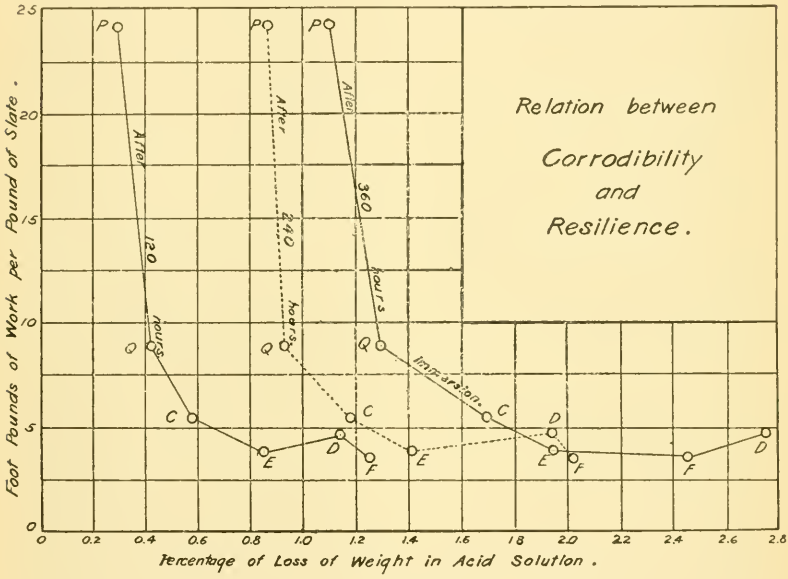

Fig. 2.

these properties; that the results found for strength and corrodibility when mentally combined give on the whole an excellent idea of the value of the slate; and that an impact test with a wooden ball shows both strength and toughness, while it at the same time indicates the capacity for resistance to corrosion. The impact test may be therefore recommended, if only a single test is to be used, as one that can be quickly and cheaply made and one likely to give reliable information of the comparative value of different kinds of slate.

CORRESPONDENCE.

George P. Merrill, Esq.,* writes that he notes with great pleasure the fact that Prof. Merriman has been enabled to continue the good work begun two years ago, and to which reference has already been made. For some years past he has been prevented from doing any original work bearing upon the subject, but he has nevertheless retained sufficient interest in the matter to appreciate the work of others. In the two papers which Prof. Merriman has now given the Society, the subject has been gone over so thoroughly as to leave but little to be said which will bear directly upon the matter, and he may, therefore, perhaps be excused in making a slight digression.

The ordinary roofing slates occupy a very interesting position in the lithologic series. Thrown down originally in the form of fine silt on a sea bottom, they owe their fissile character, not to sedimentation, but to compressive and shearing forces as manifested in the foldings incident to the formation of mountain chains. The cleavage property is therefore in no way dependent upon the original bedding. The slates of northeastern New York, as it happens, do cleave very nearly parallel to this bedding; those in Northampton County, Pa., on the other hand, as found in various quarries, or at times in the same quarry, cleave at all angles with the bedding. Now this process of shearing, while developing the cleavage, has also brought about other structural modifications in the slate, which, while not so readily manifest, are nevertheless of great importance. If we examine these slates in thin sections under the microscope, we find that in nearly every case the individual particles of quartz, feldspar, clayey matter, etc., of which they are made up, are more or less elongated, and arranged with their longer axes parallel with the plane of cleavage. In fact, it is this parallel arrangement of the particles that permits the separation of the slate into thin sheets with smooth surfaces. This arrangement of the constituent particles we have reason for believing was brought about by the shearing forces above alluded to. But this is not all. Pressure generates heat, and all rocks lying in the ground contain more or less moisture. It is not surprising therefore, that other changes than those of structure have been produced, particularly in the older slates, and those where dynamic agencies have been most active. In fact, a process of recrystallization is established, and new minerals formed, though it may be in sizes that are extremely minute. Not to go too much into detail, it can be said, that in short, the clay slates pass by imperceptible gradations into crystalline

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schists, and, further, that so far as the writer's present experience goes, the more crystalline the rock is, other things being equal, the tougher, less absorptive and more durable it is. This is well exemplified in the Peach Bottom slates referred to in Prof. Merriman's paper. These are among the most highly metamorphosed of any of the fissile argillites that are used for roofing purposes. The microscope shows in them incipient crystallizations of chiastolite and other aluminous silicates, which tend to give them strength and elasticity. Unfortunately this crystallization seems to a certain extent to interfere with the fissile property, slates of this nature yielding thicker slabs and with less even surfaces. Such, while more desirable, demand, on account of their greater weight, additional strength in roofing timbers. In the few cases in which the writer has been called upon to decide as to slates for roofs of public buildings, his decision has been invariably based upon amount of crystallization as shown by the microscope, and the presence or absence of free carbonates of lime and magnesia, sulphides of iron, or of carbonaceous matter. The "acid tests" made by Prof. Merriman serve well to show the presence of the free carbonates, the slates becoming brittle because these soluble constituents were removed. The presence of iron pyrites is indicated by the sulphur in the analyses, though it is possible that a portion of it may exist in other combinations. For this reason it would seem that the table given (page 535) is a trifle misleading, a portion of the iron there tabulated as a silicate probably existing as a sulphide.

In conclusion the writer says that he regards these tests as of very great importance, and congratulates Prof. Merriman on having discovered so simple a test as that of impact with a wooden ball, which apparently promises so much.

F. Lynwood Garrison, Assoc. M. Am. Soc. C. E., notices but one point to criticise in Prof. Merriman's excellent paper, and that is in regard to his corrosion tests. They seem to be unduly severe, and hardly to give a fair indication of the practical durability of roofing slate under ordinary circumstances. Although the atmosphere of large cities contains very small but variable quantities of certain gases, such as carbonic acid, sulphuric anhydride and some free chlorine, their corrosive action upon slate roofs, even under the most favorable circumstances, is, in the writer's judgment, extremely slight. The action of frost in breaking up and disintegrating the laminæ of the slate must be much more destructive in this irregular and variable climate. It would seem, therefore, that a freezing test would have much practical value, although such experiments are by no means easy or convenient to make. The practice of an impact test by means of dropping a ball from a fixed height upon the slate seems a good idea, possessing the advantage of being easily and quickly applied. It would seem, moreover, that such a simple test would be all required, since a fair idea of

the strength, toughness and capacity to resist shock are about the only essential factors to be determined in selecting a slate for ordinary roofing purposes.

E. H. S. Bailey, Esq., writes that some months ago Prof. Merriman asked him in reference to the analyses of the samples of slate that he made in Lehigh University several years ago. He does not think that he published the analyses, except in a popular article. He has looked them up and gives them herewith :

	Index of Porosity.	Sulphur.	CO_2	$CaCO_3$.	Specific Gravity.
Chapman's, Pa.....	0.14	.88	3.40	7.73	2.79
Chapman's Mixed.....	0.11	.98	2.83	6.43	2.79
Red Vermont.....	0.21	.075	5.42	12.32	2.81
Daniels' Quarry.....	0.14	1.29	2.72	6.18	2.78
Belfast Quarry.....	0.25	1.52	2.82	6.41	2.80

In these analyses the porosity is determined by finding how much water the slate will absorb in a given time. The sulphur represents all the sulphur, both that as sulphides and as sulphates ; the calcium carbonate is calculated from the carbonic anhydride, and the specific gravity is determined with considerable care on a specimen several grams in weight. In the expression, "Chapman's Mixed," a sample made up of specimens from different parts of the quarry is referred to so as to represent the whole fairly. The "Chapman" was simply one average sample.

The amount of calcium carbonate stated in the paper is smaller than the writer reported. In his results the calcium carbonate was calculated from the carbonic acid, which was determined.

Mansfield Merriman, M. Am. Soc. C. E., in closing the discussion, says that he agrees with Mr. Merrill as to the great value of microscopic examinations of slates and stones. Chemical analyses usually give little information as to the actual lithological composition of rocks, and it is apparent that the manner in which any element, such as sulphur, for example, exists in combination, is fully as important as the figures indicating the percentage of that element. If chemists would endeavor to give their results in such a form that the mineralogical character of the stone can be fairly inferred, instead of noting merely the substances actually determined in the analysis, their reports would be far more valuable.

With respect to the impact test it may be added that the slates were placed in a vertical plane, while the wooden ball was swung as a pendulum, its point of suspension being about 6 ft. above the specimen. The work done in one blow of the ball was its weight multiplied by the height of the vertical fall, which in each case was 9 ins.

Mr. Garrison refers to the acid tests as unduly severe. This is true, but it was the intention to make them so, in order, if possible, to obtain a better idea of the relation between resilience and corrodibility. A practical acid test, such as used for the main series on the Peach Bottom specimens, need be only from 48 to 60 hours with a solution of the strength stated. A freezing test would undoubtedly, as Mr. Garrison suggests, be an excellent one, particularly if it could be applied to slates fastened down somewhat after the manner they usually are upon roofs.

The large amount of carbonate of lime given by Professor Bailey for the red Vermont slates seems surprising in view of their well-known capacity to resist weathering. This is another illustration of how little a chemical analysis really tells regarding the physical qualities of slate. The best test of all, to compare several kinds of slate, is, of course, to put them on a roof in a manufacturing town, and then to examine them every five years until a satisfactory conclusion is reached. This in general being impracticable, it seems that the next best method is to investigate their physical properties by means of tests of strength, resilience and corrodibility, assisted if possible by microscopic examinations.

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